AISSMS
INSTITUTE OF INFORMATION TECHNOLOGY (IOIT)

ADDING VALUE TO ENGINEERING
An Autonomous Institute Affiliated to Savitribai Phule Pune University
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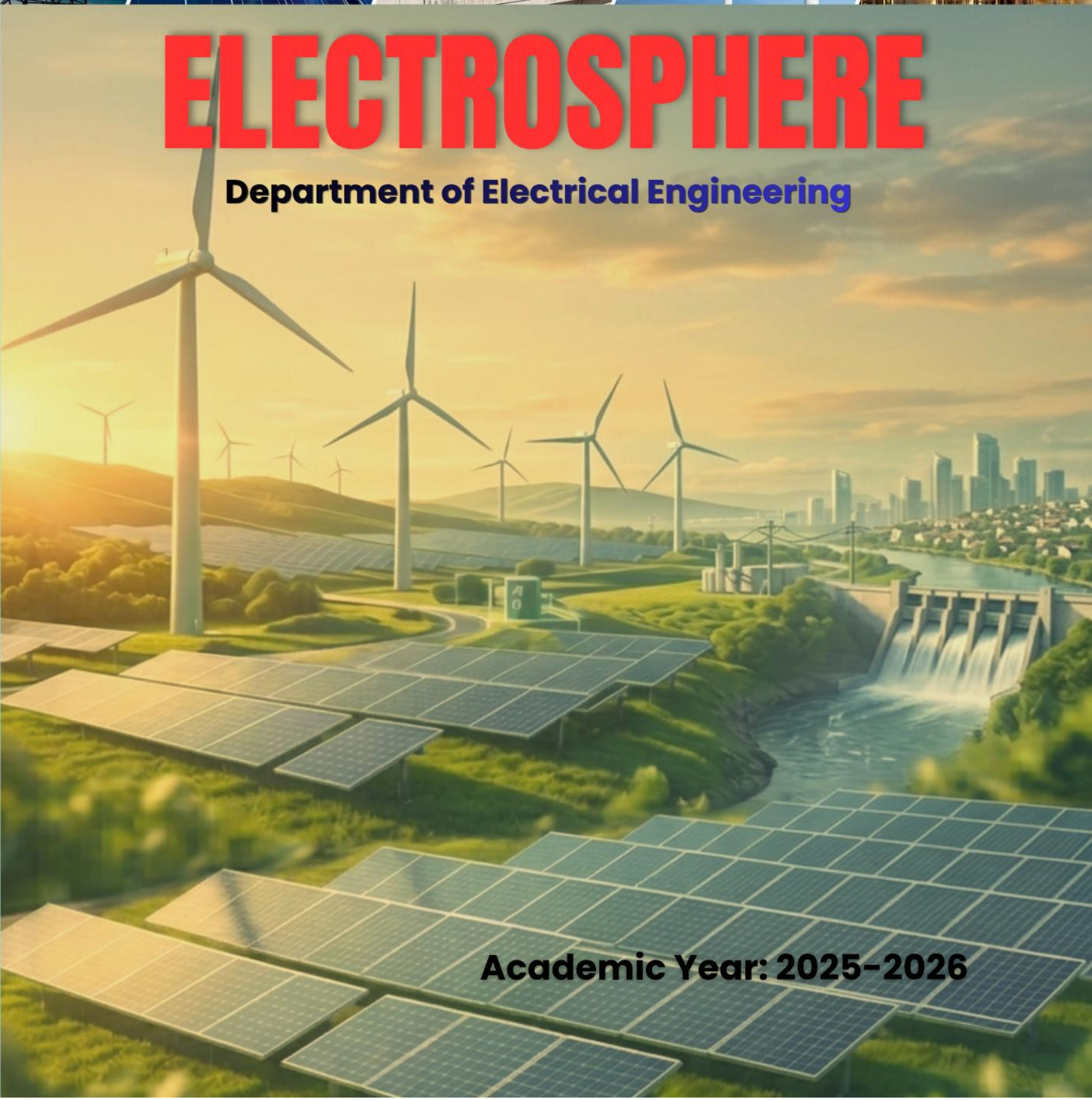
Accredited by NAAC with "A+" Grade | MBA - 5 UG Programmes

ELECTROSPHERE

Department of Electrical Engineering



Academic Year: 2025-2026

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ABOUT DEPARTMENT OF ELECTRICAL ENGINEERING

Welcome to the Department of Electrical Engineering at AISSMS IOIT, Pune.

Established in 1999, the department offers a dynamic academic environment with undergraduate programs in Electrical Engineering and postgraduate programs in Power Electronics and Drives. Our team comprises 13 dedicated faculty members and 6 highly qualified technical staff, committed to academic excellence and holistic student development. The faculty also actively contributes to various administrative and academic initiatives both within the institute and at broader levels.

The vision of the department is to contribute to society by imparting quality education in the field of electrical engineering and prepare students to succeed in their professional careers by inculcating in them high human values.

The mission of the department is to nurture globally competent electrical engineers through experiential learning, industry-institute interaction, and professional activities that enhance technical expertise, research aptitude, employability, and ethical commitment to address emerging global challenges and serve society.

The Department offers around 30 diverse courses covering core and emerging areas of Electrical Engineering. Faculty and students actively engage in academic and research activities across key domains such as Power Systems, Control Systems, Power Electronics, Electrical Machines, Renewable Energy Systems, and Power Quality.

To support hands-on learning and innovation, the department is equipped with state-of-the-art laboratories and advanced computational facilities. A wide range of industry-relevant software tools—including MATLAB, PSCAD, ETAP, EDSA, FLUKE Power Log, Fluke Energy Analyze Plus, Janitza GridVis Ultimate Planner, and Elspec PQSCADA Sapphire—are available to facilitate high-impact projects and research in various fields of Electrical Engineering.

Over the past five years, the department faculty members have been awarded several major and minor research grants from BCUD, SPPU, and AICTE. These initiatives have significantly contributed to the establishment of a **Center of Excellence in Power Quality**. A notable outcome is the **indigenously developed D.M. Tagre Power Quality Experience Center**, which has garnered interest from leading industries.

Additionally, the department has received funding support for conducting a variety of faculty development programs, student workshops, and national-level conferences, fostering a vibrant academic and research culture.

Industry-Institute Interaction plays a vital role in bridging the gap between academic learning and real-world industrial practices. The Department of Electrical Engineering actively collaborates with industries to provide students and faculty with exposure to current technologies, trends, and professional practices.

Through industrial visits, expert lectures, internships, sponsored projects, and Memoranda of Understanding (MoUs) with leading companies, students gain hands-on experience and practical insights beyond the classroom. These initiatives not only enhance employability but also encourage innovation and problem-solving aligned with industry needs . Our major recruiters are Neilsoft, Konecrane, TCS, Godrej, Conentrix and Birlasoft. Our Alumni have made excellent contributions in various fields like entrepreneurship, industry, and academics.

A culture of healthy competition and teamwork is actively cultivated within the department to enhance students' leadership and interpersonal skills. This is achieved through active participation in various professional bodies such as the **Institution of Engineers (India) – IEI**, **Institute of Electrical and Electronics Engineers (IEEE)**, **Indian Society for Technical Education (ISTE)**, **Renewable Energy Club (REC)**, and the **Electrical Engineering Students' Association (EESA)**.

These professional bodies regularly organize a wide range of co-curricular and extracurricular activities, including technical events, workshops, seminars, and competitions, providing a platform for students to showcase their talents and enhance their professional skills. Participation in such events ensures that both UG and PG students experience holistic development, equipping them with the skills and confidence needed to excel in their careers.

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Mr. R. R. Waghulde	Mrs. D. D. Changan	Mr. A. A. Joshi		

Technical Articles

1 New Trends in Electrical Engineering- Power Intelligent Future

Introduction:

The Electrical engineering field is no longer limited to power generation, transmission and distribution. With the integration of digital technologies, automation, artificial intelligence and sustainable development goals, the field is evolving rapidly. Today's electrical engineers are not just power engineers but they are also system designers, data analysts and innovators shaping the future of energy. This article explores the most impactful trends redefining electrical engineering and how they align with the industry demands.

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1. Smart Grids and Digital Power Systems

Traditional power grids are transforming into **smart grids**, integrating communication and control technologies.

Key Features:

- Real-time monitoring using IoT sensors
- Automated fault detection and isolation
- Bidirectional power flow (important for renewable sources)

Quote: "The future grid is not just electric—it is intelligent.

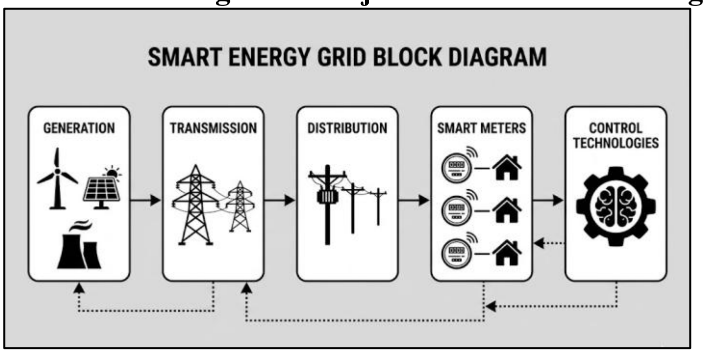

Image 1. Block Diagram of Smart Grid and Digital Power Systems

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2. Renewable Energy Integration

With increasing environmental concerns and recent unconditional international wars have resulted in the rapid growth of global transition towards renewable sources like solar and wind which are dominating power systems.

Trends:

- Solar rooftop systems
- Hybrid energy systems (Solar + Grid + Battery)
- Grid-connected inverters with control strategies

Quote: "Renewables are not the future—they are the present reality of power systems."

Image 2. Renewable Energy Integration

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3. Flexible AC Transmission Systems (FACTS) & VAR Compensation

Reactive power control is becoming crucial for efficient power systems. The exact amount of VAR compensation is now playing essential role in the industrial sector leading to future scope in residential and commercial supply system as kVAh billing has been introduced by MSEDCL.

Key Technologies:

- Static VAR Compensator (SVC)
- STATCOM
- Thyristor Controlled Reactor (TCR)

Real-World Relevance:

Used in industries to maintain power factor and reduce losses directly linked to modern panel design and PQ improvement.

Quote: "Reactive power may be invisible, but its impact on efficiency is undeniable."

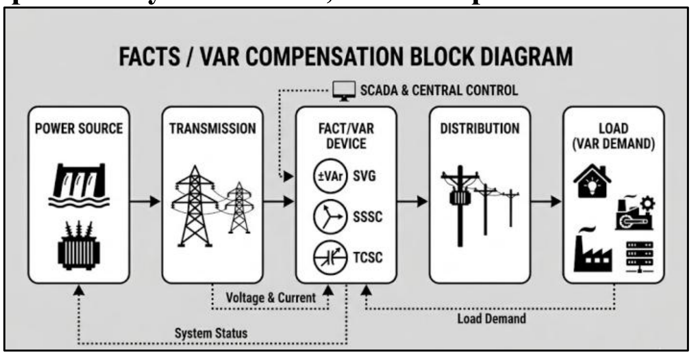

Image 3. Block Diagram of typical FACTS/ VAR Compensation System

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4. Automation and Industrial Electrification

Automation is replacing manual operations in industries.

Key Technologies:

- PLC (Programmable Logic Controller)
- SCADA systems
- Smart sensors and actuators

Industry Use:

- Automated panel manufacturing
- Smart energy monitoring systems

Quote: "Automation is not about replacing humans—it's about enhancing precision and efficiency."

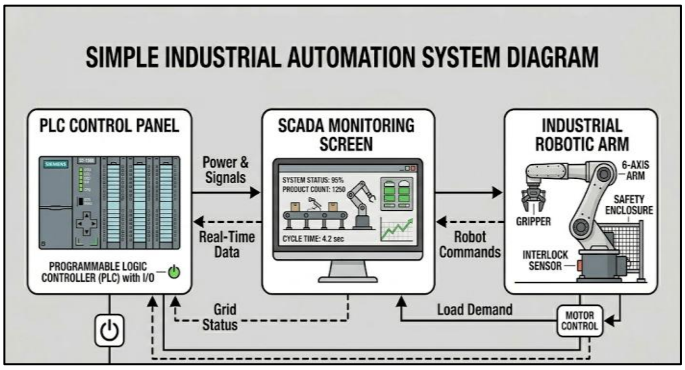

Image 4. Automation and Industrial Electrification

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5. Electric Vehicles (EVs) and Charging Infrastructure:

The shift toward electric mobility is creating new opportunities for electrical engineers. Electric Vehicles are now trending in market due to fossil fuel shortages.

Important Areas:

- Fast charging stations
- Battery management systems (BMS)
- Power electronics converters

Impact:

- Increased demand for power system upgrades
- Load management challenges

Quote: "Electric vehicles are not just a trend—they are a transformation of the energy ecosystem."

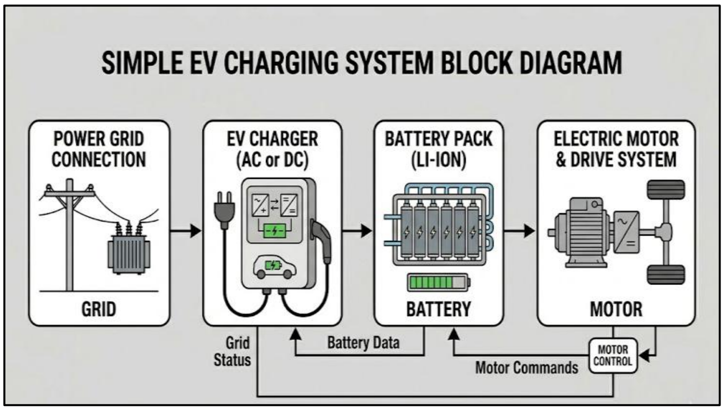

Image 5. EV Charging System

Conclusion:

The field of electrical engineering is undergoing a paradigm shift—from conventional power systems to intelligent, sustainable, and automated networks. For final-year students, understanding these trends is essential not only for academic growth but also for industry readiness.
Engineers today must combine **core electrical knowledge with modern technologies** like IoT, automation, and data analytics to stay relevant in this evolving landscape.

Final Thought: "An electrical engineer of today must design not just circuits, but intelligent and sustainable systems for tomorrow."

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2 IoT in Electrical Engineering: Transforming Smart Homes and Industries

Electrical engineering is not just limited to traditional energy generation but has moved on and uses modern digital technology like IoT, artificial intelligence, and cloud computing. The term IoT implies a connected web of devices that have the capacity to sense information and communicate it through the internet. In electrical engineering, it brings about automation, control, and real-time information. Its influence can be seen prominently in smart homes and industries where energy consumption has been greatly impacted.

IoT-based electrical systems function through the coordination of several key components, including sensors, communication networks, processing units, and cloud platforms. Sensors are used to measure electrical parameters such as voltage, current, power factor, and energy consumption. The collected data is transmitted through communication technologies like Wi-Fi, Zigbee, and LoRa. Microcontrollers such as Arduino and ESP32 process this data and execute control operations. Cloud platforms further store and analyze the data, enabling remote monitoring, predictive maintenance, and energy optimization. Additionally, user interfaces such as mobile applications provide convenient access for monitoring, control, and alert generation.

Fig. IoT-Based Smart Home System Architecture

In industrial applications, IoT significantly improves efficiency, reliability, and automation. Predictive maintenance systems use sensors to monitor equipment conditions such as temperature, vibration, and current, helping to prevent unexpected failures. IoT-enabled power monitoring systems analyze parameters like voltage, harmonics, and power factor, ensuring better energy management and compliance with standards. Integration with smart grids enhances load management, while Industrial IoT (IIoT) combined with SCADA systems enables real-time monitoring, remote control, and improved productivity.

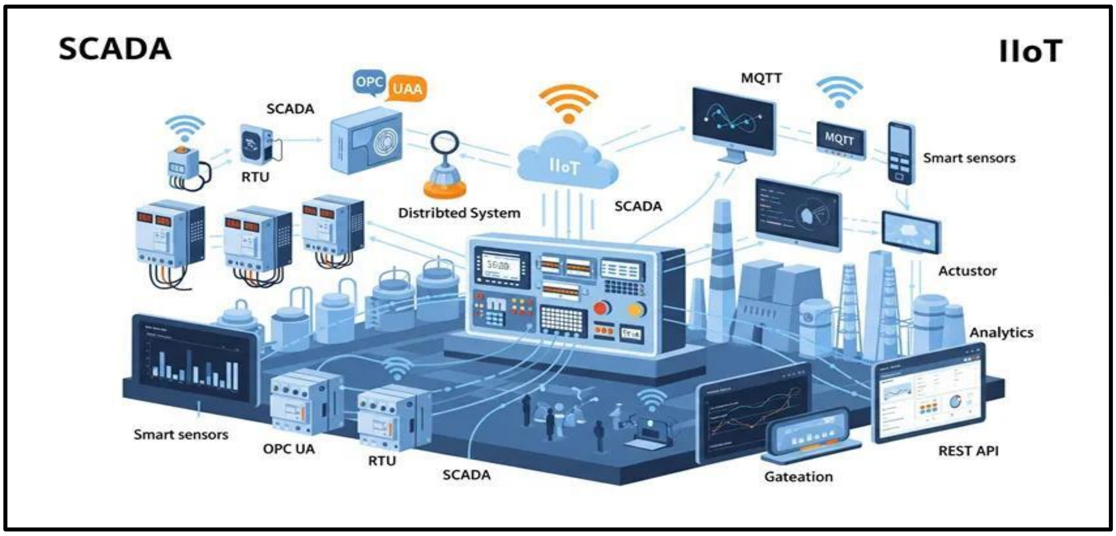

Fig. Industrial Automation

The adoption of IoT in electrical engineering offers several advantages, including enhanced energy efficiency, improved system reliability, and reduced operational costs. Real-time monitoring enables faster and more informed decision-making, while automation reduces human intervention and minimizes errors. IoT also supports sustainability by facilitating the integration of renewable energy sources and optimizing overall energy consumption.

However, the implementation of IoT is not without challenges. Issues such as cybersecurity risks and data privacy concerns remain significant, as interconnected systems can be vulnerable to attacks. High initial investment costs and compatibility issues between different devices and communication protocols can also hinder adoption. Moreover, the effectiveness of IoT systems depends heavily on stable and reliable communication networks.

In the future, the potential for IoT in electrical engineering seems bright, especially due to the increased incorporation of artificial intelligence for better decision making and development of smart grids and microgrids. Renewable energy systems being incorporated into IoT also contribute to its importance. Edge computing and 5G technology would help increase the speed and efficiency of these IoT systems. In conclusion, IoT is playing a transformative role in electrical engineering by enabling intelligent, connected, and efficient systems. It enhances convenience, safety, and energy management in smart homes, while improving reliability, reducing downtime, and optimizing operations in industries. As technology continues to advance, IoT will be essential in building sustainable and smart electrical infrastructures, provided that challenges related to security and interoperability are effectively addressed.

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3 Hydrogen Fuel: The Catalyst Accelerating a Sustainable Future

A catalyst is a small force that brings a big change. In today's world, where climate change, energy demand, and pollution challenge our future, hydrogen fuel stands out as a true catalyst—quietly powerful, clean, and transformative. Hydrogen is the most abundant element in the universe, yet its potential on Earth is only beginning to be unlocked. As a fuel, hydrogen has the ability to revolutionize how we produce, store, and use energy. It does not emit carbon dioxide when used—only water vapor—making it a key solution in the journey toward a sustainable future.

Just like a catalyst triggers a reaction without being consumed, hydrogen enables change without harming the environment. When hydrogen is used in fuel cells, it reacts with oxygen to produce electricity, heat, and water. This simple reaction can power vehicles, industries, and even entire cities—without smoke, noise, or pollution.

Hydrogen has the power to connect renewable energy sources like solar and wind with real-world applications. Excess electricity generated from renewables can be used to produce green hydrogen, which can be stored and used when energy demand is high. This makes hydrogen a bridge between clean energy generation and reliable energy use.

Hydrogen fuel can transform transportation. Hydrogen-powered vehicles offer long driving ranges, quick refueling, and zero emissions. In heavy industries such as steel, cement, and chemicals—where carbon emissions are hard to eliminate—hydrogen acts as a clean substitute for fossil fuels.

In this way, hydrogen becomes a catalyst not just for energy, but for industrial innovation and environmental responsibility.

India's Role in the Hydrogen Revolution

India's growing energy demand and commitment to sustainability make hydrogen especially relevant. Through initiatives like the Green Hydrogen Mission, India aims to reduce dependence on fossil fuels, enhance energy security, and generate green employment opportunities. With abundant solar resources and a strong engineering base, India has the potential to become a global hydrogen hub.

Progress does not happen by accident—it is ignited by ideas that challenge the norm. Hydrogen fuel represents one such idea. Though simple in composition, its impact is transformative. By enabling clean energy, supporting innovation, and redefining sustainability, hydrogen truly embodies the theme "Catalyst." It reminds us that even the smallest element can spark the greatest change.

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4 Smart Grid and Intelligent Power System

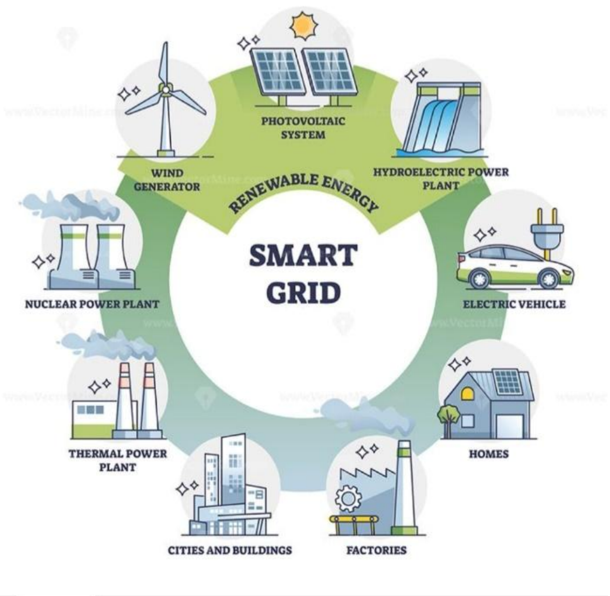
Introduction

In recent years, the field of electrical engineering has witnessed a significant transformation due to the integration of digital technologies with traditional power systems. Among the various emerging innovations, Smart Grids stand out as one of the most impactful and promising trends. A smart grid is an advanced electrical power system that uses communication, automation, and control technologies to efficiently manage electricity generation, transmission, and consumption. It plays a crucial role in building a reliable, sustainable, and intelligent energy infrastructure for the future.

Concept of Smart Grids

A smart grid is an upgraded version of the conventional power grid. Unlike traditional systems that operate in a one-way flow of electricity, smart grids enable two-way communication between power providers and consumers. This means electricity and information flow simultaneously, allowing real-time monitoring and control of the entire system.

Smart grids use technologies such as sensors, smart meters, communication networks, and advanced control systems to improve efficiency and reduce energy losses. These systems can automatically detect faults, isolate problem areas, and restore power quickly, ensuring a stable electricity supply.



Key Features

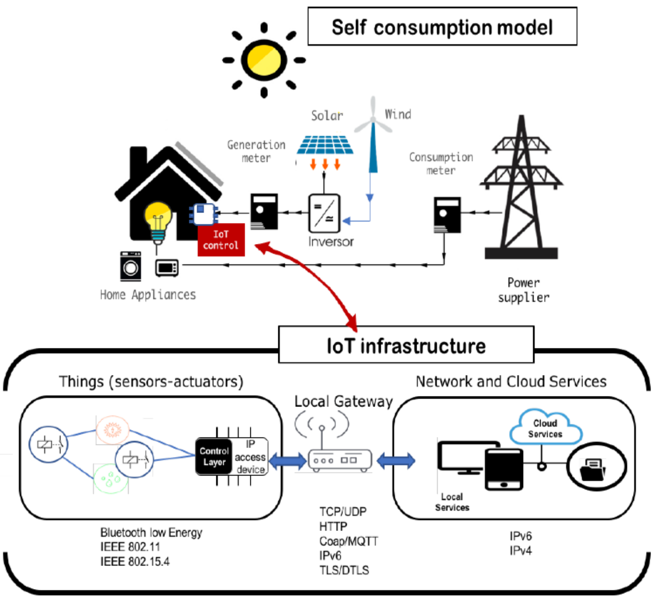
One of the most important features of smart grids is real-time monitoring. Engineers and utility providers can track energy usage and system performance instantly. Another key feature is self-healing capability, where the system can detect and correct faults without human intervention.

Smart grids also support integration of renewable energy sources like solar and wind power. Since these sources are variable in nature, smart grids help in balancing supply and demand effectively. Additionally, demand response management allows consumers to adjust their electricity usage during peak hours, reducing the load on the system.

Advantages

Smart grids offer numerous advantages over conventional power systems. They significantly improve energy efficiency by reducing transmission losses and optimizing power distribution. They also enhance reliability, as faults can be detected and resolved quickly.

Another major benefit is environmental sustainability. By supporting renewable energy and reducing wastage, smart grids help in lowering carbon emissions. Consumers also benefit through better energy management, lower electricity bills, and improved awareness of their consumption patterns.



Applications

Smart grids are widely used in modern urban infrastructure, including smart cities, industrial power systems, and residential areas. Smart meters installed in homes provide detailed information about energy usage, enabling users to make informed decisions.

In industries, smart grids help in improving operational efficiency and reducing downtime. They are also essential for supporting emerging technologies like electric vehicles, where efficient charging and load management are required.

Future Scope

The future of smart grids is highly promising. With advancements in Artificial Intelligence, Internet of Things (IoT), and data analytics, smart grids will become even more intelligent and autonomous. These technologies will enable predictive maintenance, accurate load forecasting, and enhanced decision-making.

As the demand for clean and reliable energy continues to grow, smart grids will play a vital role in transforming the global energy landscape. They are expected to be a key component in achieving sustainable development goals and creating a smarter, greener future.

Conclusion

Smart grids represent a revolutionary advancement in electrical engineering, combining power systems with modern digital technologies. They offer improved efficiency, reliability, and sustainability compared to traditional grids. As the world moves towards smarter energy solutions, understanding and implementing smart grid technology will be essential for future electrical engineers. This trend not only enhances the performance of power systems but also contributes to environmental protection and energy conservation.

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5 Catalyst: Igniting Change Through Emerging Technology

Technology is changing fast, and a lot of it comes from these emerging trends that speed things up without forcing anything. Like, intelligent systems and decentralized stuff are playing a big role now. They connect in ways that make small ideas grow into something huge. I think thats the catalyst part, accelerating what was already there. Artificial intelligence is leading the way, especially with generative models and autonomous things. Stuff based on transformer architecture helps machines get language, images, even what people mean. Its not just chatbots anymore. In engineering, AI optimizes circuit designs, predicts failures in equipment, and handles decisions in real time for smart grids or factories. It feels like AI has shifted from being a simple tool to more of a partner in the work.

Edge computing fits right in with that. Instead of sending everything to the cloud, processing happens closer to where the data comes from. This matters for low latency needs, like in self-driving cars, health devices with IoT, or automation in industries. Pair it with AI, and you get systems that decide things on the spot, cut down on dependencies, make everything more reliable out in the real world. It seems kind of obvious why thats picking up. Then theres digital twins, which are basically virtual copies of physical things, synced with real-time data. Engineers use them to simulate from battery packs in EVs to whole cities. You can test scenarios without any actual risk. This speeds up prototyping, helps with maintenance predictions, optimizes how things perform. Imagination turns into real results that way, I guess. But it gets a bit messy explaining how it all ties into daily engineering cycles.

Sustainable tech is another area thats evolving, with climate stuff in mind. Advanced energy storage, smart grids, carbon capture, those are getting more attention. Designers treat efficiency as a must, not extra. In materials science or battery management, even small tweaks lead to big environmental shifts. Renewables integration is key too. It feels like incremental changes here act as real catalysts for larger scale stuff. Human-centered design is expanding in engineering too. Its not just about how well something performs, but usability, access for everyone, and overall impact on society. Things like assistive tech, AR or VR for learning, inclusive platforms show empathy driving innovation. When tech matches human needs better, people adopt it quicker. That part stands out, kind of naturally accelerates change.

Breaking down silos with interdisciplinary work is significant. Electrical engineers team up with data scientists, mechanical folks with AI experts, even entrepreneurs and policymakers mix in. The real energy happens at those intersections, not inside old boundaries. Solutions that matter come from fusing different fields. Progress isnt just about getting bigger, its about that initial spark. An algorithm, a circuit redesign, some novel idea can set off chains across industries. In this fast tech world, engineers carry that potential. Change is coming anyway, the question is who lights it next. I might be oversimplifying, but it seems like everyones got a role in igniting it.

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6 Smart Grid

Instroduction

A smart grid is an advanced electrical power system that uses digital communication, sensors, and automation to monitor and manage the generation, transmission, and distribution of electricity efficiently. It improves reliability, reduces losses, and supports the integration of renewable energy sources.

Need for Smart Grid

Traditional power grids are one-way systems with limited monitoring and control. Growing electricity demand, renewable energy integration, power losses, and frequent outages create the need for a smart grid. Smart grids enable real-time monitoring, better demand management, and improved power quality.

Historical Development

Conventional grids were developed in the early 20th century for centralized power generation. With advancements in communication technology, sensors, and computing, smart grid concepts emerged in the late 1990s. Modern smart grids combine power systems with information and communication technology (ICT).

Basic Concept of Smart Grid

A smart grid works on two-way communication between utilities and consumers. Sensors and smart meters collect real-time data, which is analyzed to control power flow, detect faults, and balance supply and demand automatically.

Key Components of Smart Grid

Smart meters, sensors, communication networks, control centers, automated substations, and advanced software systems form the core components. These components work together to ensure efficient monitoring and control of the power system.

Communication Technologies Used

Smart grids use communication technologies such as fiber optics, wireless networks, power line communication (PLC), and the internet. These technologies allow fast and reliable data exchange between grid components.

Demand Response Management

Demand response allows consumers to adjust electricity usage based on price signals or grid conditions. This helps reduce peak load, prevents overloading, and improves overall system efficiency.

Integration of Renewable Energy

Smart grids support renewable energy sources like solar and wind by managing their variable output. Advanced forecasting, energy storage systems, and automated controls help maintain grid stability.

Role of Smart Meters

Smart meters record real-time energy consumption and enable two-way communication between consumers and utilities. They help in accurate billing, energy monitoring, and consumer awareness.

Energy Storage in Smart Grid

Energy storage systems such as batteries, pumped hydro, and supercapacitors store excess energy and supply it during peak demand. Storage improves reliability and supports renewable energy integration.

Advantages of Smart Grid

Smart grids reduce power losses, improve reliability, enhance power quality, enable renewable integration, and empower consumers. They also help in faster fault detection and restoration

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Challenges and Limitations

High initial cost, cybersecurity risks, data privacy issues, and complex infrastructure are major challenges. Skilled manpower and proper regulations are also required for successful implementation.

Applications of Smart Grid

Smart grids are used in smart cities, electric vehicle charging, renewable energy systems, industrial automation, and modern power distribution networks.

Future Scope and Conclusion

Smart grids are essential for sustainable and efficient power systems. With advancements in AI, IoT, and energy storage, smart grids will play a crucial role in future energy management and global energy sustainability.

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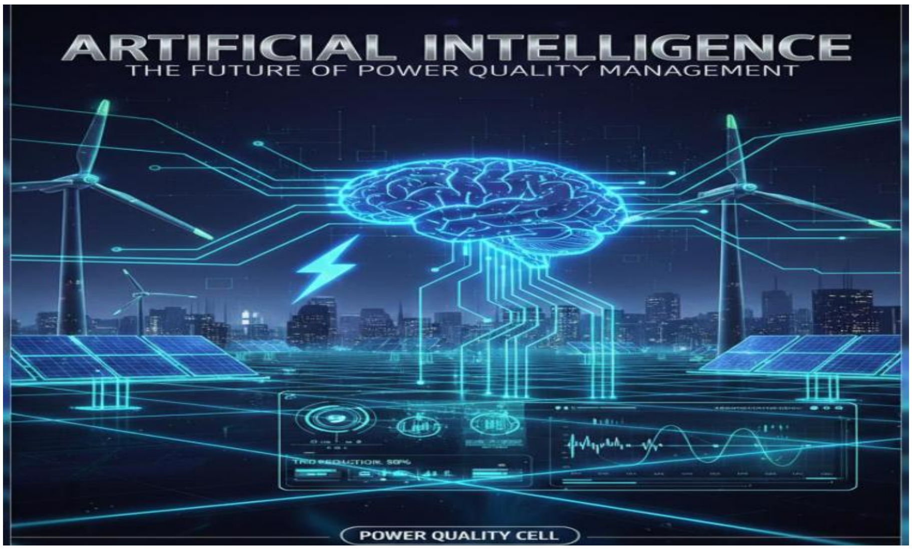
7 AI Applications in Power Quality Systems

Introduction

In the modern era of the "Smart Grid," the traditional methods of monitoring power quality are facing significant challenges. With the influx of non-linear loads, inverter-based renewable energy sources (like solar and wind), and the rapid expansion of EV charging infrastructure, power disturbances have become more frequent and harder to predict.

Power Quality (PQ) refers to the ability of electrical equipment to function correctly despite disturbances in the voltage, frequency, or current. Traditionally, detecting these issues required manual analysis of waveforms. However, Artificial Intelligence (AI) and Machine Learning (ML) are now transforming this field from reactive troubleshooting to proactive, intelligent management.



Key AI technologies in PQ

A. Machine Learning (ML) for Classification

The most common application is the classification of PQ disturbances like sags, swells, flickers, and transients.The Technology: Support Vector Machines (SVM) and Random Forest algorithms.The Impact: Instead of an engineer looking at a waveform for hours, the ML model identifies the fault type in milliseconds with a success rate of over 98%.

B. Deep Learning & Neural Networks

For more complex issues, Convolutional Neural Networks (CNN) are used. By converting electrical signals into visual "spectrograms," the CNN can "see" the noise in the system. This is particularly useful for identifying the specific "harmonic signature" of a failing piece of equipment

The role of predictive maintenance

One of the most valuable uses of AI is Proactive Monitoring.

Data Collection: Smart meters collect voltage and current data 24/7.

Trend Analysis: AI detects “micro-deviations” that a human would miss.

Failure Prediction: The system can predict that a transformer or capacitor bank will fail within the next 48 hours based on its thermal and harmonic trends.

Real-time harmonic mitigation

Harmonics cause overheating and reduce the lifespan of motors. AI-driven Active Power Filters (APF) use "Reinforcement Learning" to adapt to changing loads. As students switch on computers in a lab or heavy machinery in a workshop, the AI adjusts the filtering parameters instantly to keep the Total Harmonic Distortion (THD) within IEEE 519 standards.

Challenges in implementation

While AI is powerful, our Cell must consider:

Data Quality: AI requires high-frequency sampling data to be accurate.

Edge Computing: Processing AI models requires powerful hardware (like NVIDIA, Jetson or specialized microcontrollers) installed directly at the substation.

Cybersecurity: A smart grid is a connected grid, making it a target for cyber-attacks. AI must also be used to defend the grid against these threats.

Proposed student projects & research

For members of the Power Quality Cell looking to get hands-on with AI, here are three entry-level project ideas:

Project 1: IoT-Based AI Fault Logger Build a small-scale monitoring system using an Arduino or Raspberry Pi and a ZMPT101B voltage sensor. Use a basic Python script with a Scikit-learn library to classify different types of voltage sags created in the lab.

Project 2: Solar Inverter Harmonic Analysis Analyze the output of a local solar inverter. Use a Fast Fourier Transform (FFT) algorithm and an AI model to identify how the Total Harmonic Distortion (THD) changes as the sun's intensity varies throughout the day.

Project 3: Predictive Battery Health Monitor Create a "Health Score" for the UPS batteries in the computer lab. Use an AI regression model to predict the "State of Health" (SoH) based on discharge cycles and temperature data.

Conclusion

For the members of the Power Quality Cell, the message is clear: The future of Power Systems is Digital. By integrating AI, we aren't just monitoring the grid; we are making it "self-healing." This technology will ensure that the power of tomorrow is stable, efficient, and smart.

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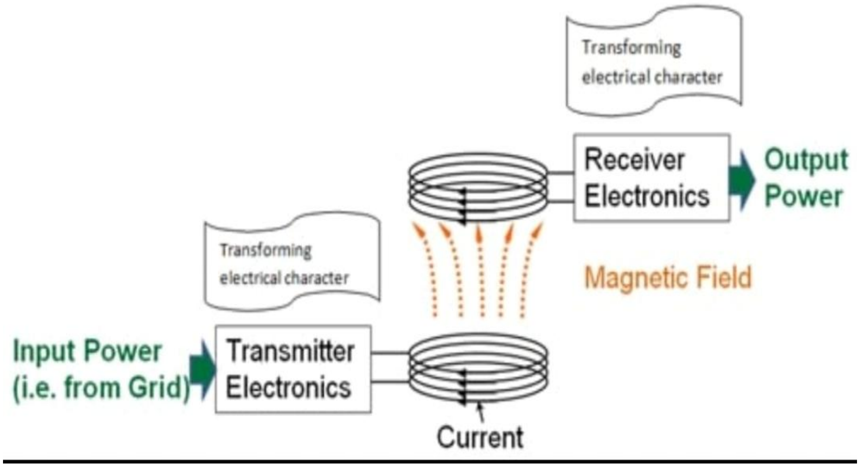
8 Wireless Power Transfer

Instroduction

Wireless Power Transfer (WPT) is a technology that allows electrical energy to be transmitted from a power source to a load without using physical wires or cables. It uses electromagnetic fields such as magnetic fields, radio waves, microwaves, or laser beams to transfer power. Wireless power transfer improves convenience, safety, and reliability, especially in modern electronic and automated systems.



Need for Wireless Power Transfer

Conventional wired power systems suffer from problems such as cable wear, sparks, power losses, limited mobility, and safety hazards in wet or explosive environments. With the increasing use of mobile devices, electric vehicles, medical implants, and automation, wireless power transfer is required to eliminate cables, reduce maintenance, and enable contactless charging.
Indian Context:
In India, dust, humidity, and voltage fluctuations damage charging cables frequently. Wireless charging helps increase device life and safety, especially in public places like railway stations and airports.

Historical Development

The concept of wireless power transfer was first introduced by Nikola Tesla in the late 19th century. He demonstrated energy transfer using electromagnetic waves. However, due to technological limitations, it was not commercially feasible at that time.

With advancements in power electronics, communication systems, and semiconductor devices, practical wireless power systems have been developed in the 21st century, especially for consumer electronics and electric vehicles.

Basic Principle of Wireless Power Transfer

Wireless power transfer works on the principle of electromagnetic induction ord electromagnetic radiation. Electrical energy at the transmitter is converted into an electromagnetic field. This field travels through air and induces an electrical current in the receiver, which is then used to power the load.

Types of Wireless Power Transfer

Wireless power transfer techniques are classified into:

- Inductive coupling
- Resonant inductive coupling
- Radio frequency (RF) or microwave power transfer
- Laser-based power transfer

Each method differs in transmission distance, efficiency, and application.

Inductive Coupling

Inductive coupling uses two coils placed close to each other. When alternating current flows in the transmitter coil, it produces a magnetic field that induces voltage in the receiver coil. This method works only over short distances.

Indian Applications:

- Wireless charging pads for smartphones
- Electric toothbrushes used in Indian households
- Contactless charging devices in hospitals

Resonant Inductive Coupling

Resonant inductive coupling improves power transfer efficiency by tuning both transmitter and receiver coils to the same resonant frequency. This allows power transfer over a longer distance compared to simple inductive coupling.

Indian Applications:

- Research projects in IITs for wireless EV charging
- Prototype wireless charging systems for electric buses
- Industrial automation systems

Microwave Power Transfer

In microwave power transfer, electrical energy is converted into microwave signals and transmitted through free space using antennas. The receiver antenna converts microwaves back into electrical energy using a rectenna.

Indian Applications:

- ISRO research on space-based solar power systems
- Wireless powering of remote sensors in defense and weather monitoring
- Smart agriculture sensor networks

Laser-Based Power Transfer

Laser-based power transfer uses focused laser beams to transmit power over long distances. The receiver uses photovoltaic cells to convert laser light into electrical energy. This method requires accurate alignment and safety precautions.

Indian Applications:

- Defense surveillance drones
- Space research experiments by ISRO
- Remote powering of sensors in inaccessible areas

Advantages of Wireless Power Transfer

Wireless power transfer offers several advantages:

- No physical connectors or cables.
- Reduced wear and maintenance.
- Improved safety in wet and hazardous environments.
- Convenience and flexibility.
- Better durability of devices.

Challenges and Limitations

Despite its benefits, wireless power transfer has some limitations:

- Limited transmission distance.
- Lower efficiency compared to wired systems.
- High initial cost.

- Electromagnetic interference is must.
- Safety and regulatory concerns are must.
- In India, high system cost and lack of standard infrastructure slow down large-scale adoption.

Applications of Wireless Power Transfer

Wireless power transfer is widely used in:

- Smartphone wireless charging.
- Electric vehicle charging.
- Medical implants like pacemakers.
- Industrial robots.
- Smart cities and IoT devices.

Real – World Applications

- Mobile phones – Wireless charging pads (Qi chargers).
- Electric vehicles – Cable-free charging while parked.
- Medical implants – Pacemakers, cochlear implants.
- Wearables & gadgets – Smartwatches, earbuds.
- Industrial & IoT sensors – Powering sensors without batteries.
- Public transport – Wireless charging of electric buses.
- Home appliances – Electric toothbrushes, shavers.

Future Scope and Conclusion

Wireless power transfer has vast potential in India due to the growth of electric vehicles, smart cities, and renewable energy systems. With continuous research, improved efficiency, and reduced costs, wireless power transfer will become a key technology for sustainable and contactless power solutions in the future.

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9 Electric Power Quality: Ensuring Reliable Energy Delivery

Introduction

Electric power quality refers to how well the voltage, frequency, and waveform of supplied electricity match established standards, ensuring stable operation for devices and systems. Poor power quality leads to equipment damage, inefficiencies, and outages, while high quality supports modern grids with renewables and EVs.

Parameters :

Power quality encompasses several measurable aspects.

- Voltage Magnitude: Steady supply within ±10% of nominal (e.g., 230V in India), preventing sags (dips below 90%) or swells (above 110%).
- Frequency Stability:
  Fixed at 50 Hz in India or 60 Hz. elsewhere, with deviations under 1% to avoid motor issues.
- Harmonics: Distortions from non-linear loads like inverters; total harmonic distortion (THD) limited to 5-8% per standards.
- Flicker and Transients: Rapid voltage changes or spikes that affect lighting and sensitive electronics. These parameters ensure sinusoidal waveforms ideal for linear loads.

International Standards

Standards define limits and measurement methods for compliance.

Standard	Scope	Key Limits wikipedia+2
IEEE 519	North America, harmonics	Voltage THD <5%, current limits by order
EN 50160	Europe, voltage characteristics	95% of values within ±10% nominal over 10-min periods
IEC 61000-4-30	Measurement methods (Class A/S)	Frequency ±0.2 Hz, includes dips, swells, interruptions
IEC 61000-2-x	Compatibility levels	THD voltage 8% general, 5% sensitive environments

Class A instruments offer highest accuracy for contracts and disputes.

Causes of Poor Quality :

Non-linear loads like LED lights, EVs, and renewables introduce harmonics and unbalance. Grid events such as faults or switching cause transients, while overloads lead to sags. In India, rapid electrification amplifies these in three-phase residential/commercial systems.

Mitigation Techniques :

Engineers deploy solutions tailored to energy audits and smart grids.

- Active filters and STATCOMs cancel harmonics dynamically.
- UPS and DVRs (dynamic voltage restorers) handle sags/swells.
- AI-driven monitoring predicts issues via smart meters, linking to 2026 grid trends.
- Capacitor banks balance three-phase systems in audits. Regular audits with portable kits measure THD and compliance

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Power quality overview

Power quality analysis is a well-established concept, used to evaluate the quality of electrical energy delivered to a customer. A simplified way to define the PQ concept is shown in Figure

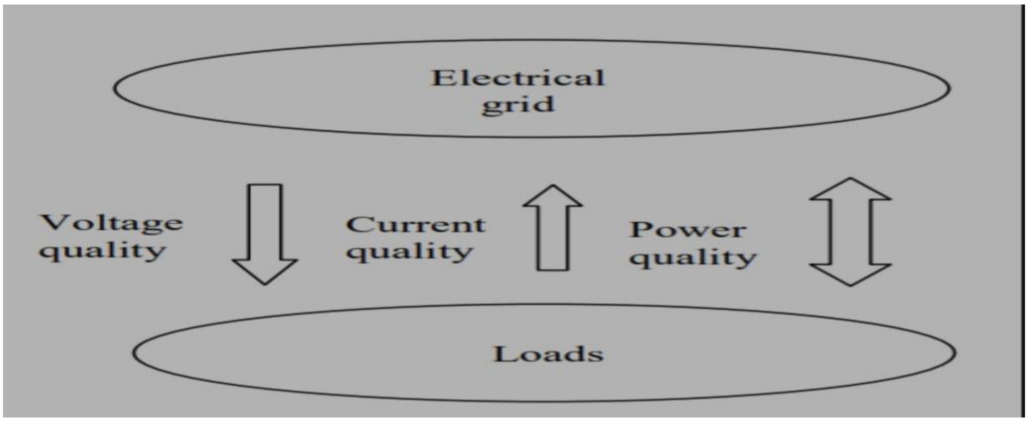
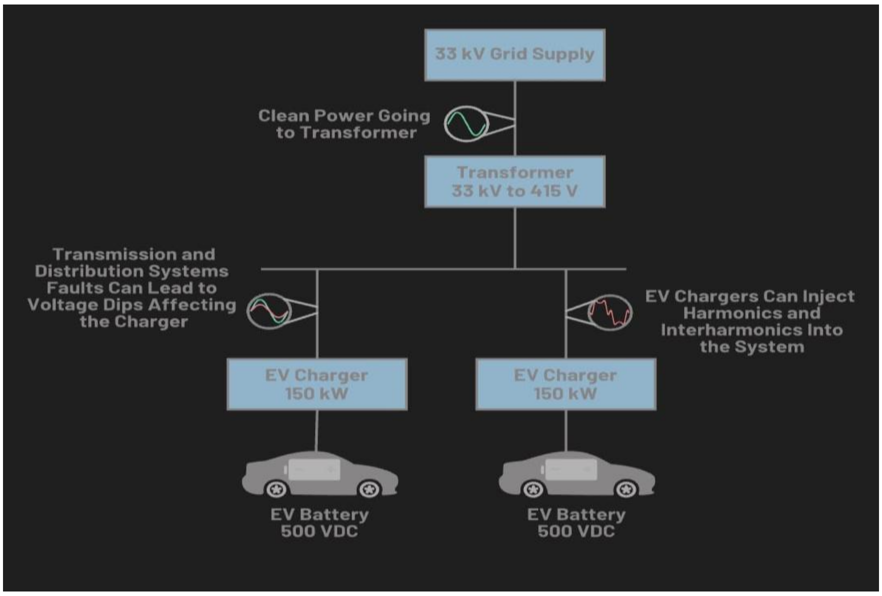


Figure . The power quality concept.

- The electrical power grid or network should be designed in such a way that the supplier is always capable of guaranteeing a certain voltage quality.
- When loads are connected the power quality is influenced more or less depending on how the electrical network is designed and on the current profile of the loads. From this perspective, a number of basic parameters for power quality have been identified which can be measured and compared with reference values.
- The reference values may be absolute values or statistical values and may be obtained from standards or agreed in a bilateral contract between network generator and a customer.

EV Chargers

EV chargers can face multiple power quality challenges, both in power sent to and from the grid (see Figure). From a power distribution company perspective, power electronics-based converters used in EV chargers inject harmonics and interharmonics. Chargers with improperly designed power converters can inject direct currents (DC). Additionally, fast EV chargers introduce rapid voltage changes and voltage flicker into the grid. From the EV charger side, faults in transmission or distribution systems lead to voltage dips or interruption of supply voltage to the charger. Reduction of voltage from the EV charger tolerance limits will lead to activation of undervoltage protection and disconnection from the grid (which leads to a very bad user experience).



Importance in 2026 :

With India's push for renewables and EVs, power quality prevents losses up to 10% in efficiency. It supports stable smart grids optimized by AI for forecasting and fault detection, aligning with sustainable practices.

Compliance reduces risks in commercial setups, vital for your energy audit projects.

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10 Powering the Future: High Efficiency Solar Cells in Modern Electrical Engineering

Introduction

Solar energy is one of the most promising renewable energy sources available today. High-efficiency solar cells are designed to convert a greater percentage of incident sunlight into electrical energy. These advanced photovoltaic devices are critical for meeting global energy demands while reducing environmental impact.

Need for High – Efficiency Solar Cells

Conventional solar cells are limited by material and physical constraints. Increasing efficiency reduces land usage, lowers balance-of-system costs, and improves feasibility in space-limited applications such as rooftops and satellites.

Historical Development

The first practical solar cell was developed in 1954 with an efficiency of 6%. Over decades, improvements in silicon purity, doping techniques, and manufacturing led to efficiencies exceeding 25%. Modern research focuses on tandem and thin-film Technologies.

Basic Solar Call Theory

Solar cells operate on the photovoltaic effect. When photons strike a semiconductor, electron-hole pairs are generated, creating a potential difference and current flow when connected to a load.

Loss Mechanisms in Solar Cells

Efficiency losses occur due to reflection, recombination, resistive losses, and thermalization. High-efficiency designs aim to minimize these losses using advanced materials and structures.

Limits (Shockley – Queasier Limit)

Single-junction solar cells are theoretically limited to ~33% efficiency. Multi-junction designs surpass this limit by capturing a broader solar spectrum.

Tandem Solar Cells

Tandem solar cells use stacked layers with different bandgaps. Each layer absorbs a different wavelength range, significantly improving total efficiency.

Perovskite Solar Cells

Perovskite materials have excellent absorption properties and low fabrication costs. They have revolutionized photovoltaic research due to rapid efficiency improvements.

Perovskite – Silicon Tandem Cells

Combining perovskite with silicon enables record efficiencies above 35%. These structures are among the most promising for commercial deployment.

Triple – Junction Solar Cells

Triple-junction cells incorporate three absorber layers and are widely used in space applications due to efficiencies exceeding 40%.

Manufacturing Techniques

Techniques include chemical vapor deposition, spin coating, laser patterning, and atomic layer deposition. Scalability and stability remain major challenges.

Modifications and Enhancements

Surface texturing, passivation layers, anti-reflection coatings, and interface engineering are used to improve efficiency and lifespan.

Stability and Degradation Issues

Perovskite cells face challenges such as moisture sensitivity and thermal degradation. Encapsulation and material engineering help mitigate these issues.

Real – World Applications

Applications include satellites, electric vehicles, smart buildings, portable electronics, and large-scale solar farms.

Future Scope and Conclusion

High-efficiency solar cells are key to sustainable energy systems. Continued research will enable commercialization, lower costs, and global energy transformation.

Major High-Efficiency Solar Power Plants Around the World

1. Bhadla Solar Park — Rajasthan, India

One of the largest solar parks in the world with an installed capacity of over 2,200 MW, using advanced photovoltaic modules in a desert region with very high solar irradiance. It contributes significantly to India's renewable energy targets.

2. Noor Abu Dhabi — Sweihan, UAE

A utility-scale solar PV plant with over 1.1 GW capacity and very high production output. It uses millions of solar panels and advanced panel-cleaning systems to maintain high generation efficiency in hot, dusty conditions.

3. California Valley Solar Ranch — California, USA

A 250 MW photovoltaic power plant that deployed high-efficiency crystalline solar panels to increase conversion of sunlight into electricity over its large desert footprint.

4. Massive Solar Parks in China

China leads globally in solar generation and has built numerous ultra-large solar parks such as Gonghe Talatan Solar Park (largest by capacity — around 16,000 MW planned) and other utility solar parks in Qinghai and Ningxia provinces that use highly efficient modules and optimal siting to maximize production.

5. Combined Solar + Storage Projects — USA

New high-efficiency plants like Gemini Solar + Storage (near Las Vegas, Nevada) and Danish Fields (Texas) integrate advanced solar panels with battery energy storage, improving dispatchable power delivery and overall system efficiency.

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11 Electrical Engineering and Future Prospectus

Electrical Engineering is the core, most popular, and oldest branch of engineering. This branch deals with the application of electricity and electronics. Without electricity and consumer appliances, it is very difficult to survive. To get a better idea about the Electrical Engineering course, let us have a look at some of the important subjects present in the programme.

Core subjects in Electrical Engineering are Analog and Digital Electronics (ADE), Power Electronics (PE), Control System (CS), Electrical Machines (EM/C), Power System (PS), Power System Operation and Control (PSOC), High Voltage Engineering (EHV). Elective courses offered in electrical engineering are Renewable Energy Systems (RES), Extra High Voltage (EHV), Power Quality (PQ), Embedded systems (ES), Electric Vehicle, Digital Signal Processing (DSP). There are Professional bodies that provide literature for electrical engineers viz; Institute of Electrical and Electronics Engineers (IEEE), Institution of Engineers, and Institution of Engineering and Technology (IET).

Based on the knowledge gained electrical graduates can work on large power plants, companies which include design, manufacturing and operating power plants, electrical motors, parts of automobiles, aircraft, space crafts, and all kinds of engines. Electrical Engineering graduates can design electric circuits and appliances.

As per the placement record average starting salary of fresher is 3.6 lakh and above. They can become an entrepreneur too. Graduates can also avail benefits of Research and Development (R&D) jobs in the government sector and higher studies in the area of Control system , Power system, Power Electronics and Drives. Graduates may enter into teaching profession after completing post graduate programme. They can also go for Ph.D. programme and venture into the R&D.

The employment of electrical engineers is projected to grow in the coming years in government, public, and private sectors. Top Government public sector companies like Power Grid, DRDO, BHEL, BEL, Coal India, HPCL, HIL, EIL, BPCL, NTPC, IOCL, ONGC, Crompton Greaves Consumer Electricals Ltd., Kirloskar Electric Co Ltd., ABB India Ltd., Railway, Metro Railway and many more, offer huge employment opportunities for electrical engineering graduates. There is a huge demand for Qualified Electrical Engineers. The scope of Electrical Engineering has been grown up as compared to previous years in hardware as well as software industries. Electrical engineers play an important role in the Renewable Energy Sector which has been also called as cleantech job sectors such as Solar, Wind, Biofuel, and Smart Grid, Agricultural, etc. Government aids are available to explore such green technology where electrical engineers contribute to the extent. Now a day it can be seen that there is an impact of power quality on electrical system reliability. Electrical Engineers can provide a solution for protecting equipments and optimizing performance. There is a large scope for Electrical Engineer in providing high quality power to society.

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12 Shaping Power, Mobility and Digital Infrastructure (Recent Years)

“Electrical engineering in India is no longer limited to power generation—it now drives sustainability, smart mobility, and digital intelligence.”

Introduction

Over the last few years, electrical engineering in India has witnessed rapid and transformative growth. National missions such as *Make in India*, *Digital India*, *National Smart Grid Mission*, and *FAME* have significantly influenced research, education, and industrial practices. Electrical engineers today are key contributors to India’s transition towards clean energy, intelligent systems, and technology-driven infrastructure.

This article highlights the most impactful trends that have shaped electrical engineering in India in recent times.

1. Smart Grids and Digital Power Infrastructure

India’s conventional power grid is steadily evolving into a **smart grid** enabled with automation, sensors, and real-time communication. Advanced Metering Infrastructure (AMI), SCADA systems, and data analytics are being adopted to reduce transmission losses and improve reliability. Smart grids are particularly crucial for managing variable renewable energy sources and ensuring uninterrupted power supply.

Key Focus Areas:

- Smart meters and distribution automation
- Real-time monitoring and fault detection
- Grid resilience and reliability

2. Renewable Energy Integration and Energy Storage

India has emerged as one of the global leaders in renewable energy adoption, especially in **solar and wind power**. Integrating large-scale renewables into the grid presents technical challenges such as intermittency and voltage stability. Electrical engineers are addressing these challenges through advanced power electronics, grid-scale battery storage, and hybrid energy systems.

Emerging Opportunities:

- Solar PV and wind integration
- Battery energy storage systems (BESS)
- Microgrids for rural electrification

"Renewable integration has transformed the role of electrical engineers from operators to system optimizers."

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3. Electric Vehicles and Charging Infrastructure

The rapid growth of **electric vehicles (EVs)** in India has opened new domains in electrical engineering. Engineers are actively involved in the design of EV powertrains, battery management systems, fast chargers, and vehicle-to-grid (V2G) technology. Government incentives and increasing environmental awareness are accelerating EV adoption across the country.

Technical Domains Involved:

- Power electronics and motor drives
- Battery technology and thermal management
- EV charging stations and grid interaction

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4. AI, IoT, and Automation in Electrical Systems

Artificial Intelligence (AI) and the Internet of Things (IoT) are increasingly being integrated into electrical engineering applications. From predictive maintenance of transformers to intelligent load forecasting, data-driven decision-making has become essential. Smart substations and automated industrial systems are redefining efficiency and safety standards.

Applications Include:

- Predictive fault analysis
- Smart energy management systems
- Industrial automation and robotics

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5. Curriculum Reforms and Skill-Based Education

In recent years, **AICTE and affiliating universities** have revised electrical engineering curricula to align with industry requirements. Greater emphasis is now placed on internships, project-based learning, multidisciplinary electives, and emerging technologies. This shift ensures that graduates are industry-ready and innovation-oriented.

Academic Focus Areas:

- Industry–academia collaboration
- Hands-on laboratory training
- Emerging technology electives

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6. Indigenous Research and Innovation

Indian institutes and research organizations are increasingly contributing to indigenous technology development. Patent filings, funded research projects, and startup incubation in electrical engineering domains have grown steadily. Areas such as smart energy systems, power converters, and electric mobility are witnessing notable innovation.

Impact:

- Strengthening self-reliance
- Addressing local engineering challenges
- Enhancing global research visibility

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7. Emerging Technologies: Towards the Future

Apart from mainstream developments, India is gradually investing in futuristic areas such as **quantum technologies, advanced materials, and autonomous systems**. While still at a nascent stage, these technologies are expected to influence future electrical system design and secure communication frameworks.

Conclusion

Electrical engineering in India is undergoing a paradigm shift—moving beyond traditional boundaries to embrace sustainability, digital intelligence, and innovation. The recent trends clearly indicate a future where electrical engineers play a critical role in nation-building, technological leadership, and sustainable development.

For students, educators, and professionals, staying aligned with these trends is essential to remain relevant and impactful in this evolving engineering landscape.

Departmental Insight:
Encouraging research-driven learning and industry collaboration will be key to nurturing future-ready electrical engineers.

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13 Latest Trends in Electrical Engineering

Introduction

Electrical Engineering is undergoing a rapid transformation driven by advancements in digital technologies, renewable energy integration, and intelligent automation. Traditional power systems are evolving into smart, flexible, and sustainable networks. This article highlights the latest trends in Electrical Engineering that are shaping modern power systems, industry practices, and future career opportunities for engineering students.

1.Smart Grids and Intelligent Power Systems

The conventional power grid is being upgraded into a Smart Grid, which integrates communication, automation, and information technologies with the electrical network. Smart grids enable: - Two-way flow of power and information - Self-healing and fault- tolerant systems - Efficient demand-side management - Integration of renewable energy sources
Smart meters, advanced sensors, and automated substations are key components of this technology.

2.Integration of Renewable Energy Sources

With the global shift toward sustainability, renewable energy sources such as solar and wind power are increasingly integrated into power systems. However, their intermittent nature introduces challenges like voltage fluctuations and frequency instability.
Advanced power electronic converters, energy storage systems, and intelligent control algorithms are employed to ensure grid stability and reliable operation.

3.Power Electronics and Wide Band Gap Devices

Power electronics plays a vital role in modern electrical systems. The emergence of Wide Band Gap (WBG) semiconductors such as Silicon Carbide (SiC) and Gallium Nitride (GaN) has revolutionized converter design.
These devices offer: - High switching frequency - Higher efficiency - High temperature and voltage capability - Reduced size and losses. They are widely used in electric vehicles, renewable energy systems, and high-voltage power supplies.

4.Electric Vehicles and Charging Infrastructure

The rapid adoption of Electric Vehicles (EVs) has opened new avenues in Electrical Engineering. Key areas include: - Fast and ultra-fast EV charging stations - Vehicle-to- Grid (V2G) technology - Battery management systems - Power quality improvement
EVs not only act as loads but can also support the grid during peak demand through V2G technology.

5.Digital Substations and Advanced Protection Systems

Modern substations are becoming fully digital, using standards such as IEC 61850 for communication. Digital substations provide: - Reduced wiring and maintenance, High- speed protection and control, Improved reliability and safety, Remote monitoring and diagnostics.

Numerical relays and intelligent electronic devices (IEDs) have replaced conventional electromechanical relays.

6.Role of Artificial Intelligence and Machine Learning

Artificial Intelligence (AI) and Machine Learning (ML) are increasingly used in power system applications such as: - Load forecasting, Fault detection and diagnosis, Predictive maintenance of equipment, Optimal energy management and more

These techniques help utilities improve reliability, reduce outages, and optimize system performance.

7.Microgrids and Distributed Generation

A microgrid is a localized group of loads and distributed energy resources that can operate independently or in coordination with the main grid. Microgrids enhance: - Energy reliability, Resilience during grid failures, Integration of local renewable sources

They are especially useful in campuses, industrial parks, and remote areas.

8.Internet of Things (IoT) in Electrical Engineering

IoT enables real-time monitoring and control of electrical equipment through connected sensors and communication networks. Applications include: - Smart homes and buildings, Energy monitoring systems, Asset management, Condition-based maintenance.

IoT-based solutions improve efficiency and decision-making in power systems.

Conclusion

The field of Electrical Engineering is expanding beyond traditional boundaries, embracing digitalization, automation, and sustainability. Emerging trends such as smart grids, renewable energy integration, electric vehicles, power electronics, and artificial intelligence are redefining the profession.

For students and young engineers, understanding these trends is essential to remain industry-ready and contribute effectively to the future of energy systems.

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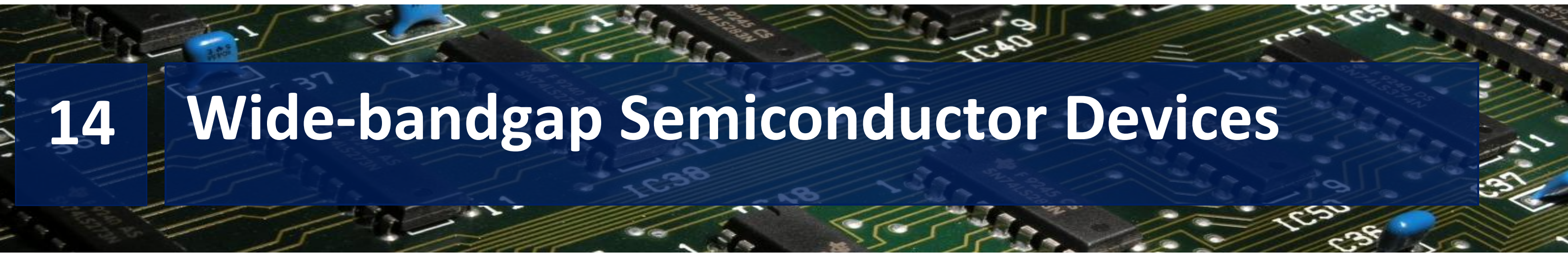

14 Wide-bandgap Semiconductor Devices

Abstract

Wide-bandgap (WBG) semiconductor devices have emerged as a transformative technology in modern power electronics due to their superior electrical, thermal, and switching characteristics compared to conventional silicon-based devices. Materials such as Silicon Carbide (SiC) and Gallium Nitride (GaN) enable higher operating voltages, faster switching speeds, and improved efficiency. This article presents an overview of wide-bandgap semiconductor materials, their device characteristics, advantages over silicon devices, applications in power electronics, future research trends and the role of WBG devices in electric vehicles, renewable energy systems, and high-frequency power conversion.

Keywords: Wide-bandgap Semiconductors, Silicon Carbide, Gallium Nitride, Power Electronics, High-Frequency Switching.

1. Introduction

The rapid advancement of power electronic systems has increased the demand for devices capable of operating at high voltage, high temperature, and high frequency with minimal losses. Conventional silicon (Si) devices face inherent material limitations under such extreme operating conditions. To overcome these constraints, wide-bandgap semiconductor materials have gained significant attention.

Wide-bandgap semiconductors possess a bandgap energy significantly larger than silicon, allowing improved breakdown voltage, reduced conduction losses, and enhanced thermal stability. These properties make WBG devices highly suitable for next-generation power electronics applications.

2. Wide-bandgap Semiconductor Materials

A semiconductor is termed a wide-bandgap material when its bandgap energy exceeds that of silicon (1.12 eV). Common WBG materials include:

2.1 Silicon Carbide (SiC)

Silicon Carbide has a bandgap of approximately 3.26 eV. It exhibits high breakdown electric field strength, high thermal conductivity, and excellent chemical stability. SiC is widely used in high-voltage and high-power applications.

2.2 Gallium Nitride (GaN)

Gallium Nitride has a bandgap of about 3.4 eV and is characterized by high electron mobility and high switching speed. GaN devices are ideal for high-frequency and medium-power applications.

---

3. Characteristics of Wide-bandgap Devices

Wide-bandgap semiconductor devices offer several superior characteristics compared to silicon devices:

- Higher breakdown voltage
- Lower switching and conduction losses
- Higher operating temperature (above 200°C)
- Higher power density
- Faster switching capability
- Reduced cooling requirements

These properties result in compact, efficient, and reliable power electronic systems.

---

4. Types of Wide-bandgap Semiconductor Devices

The commonly used WBG devices in power electronics include:

4.1 SiC Power Devices

- SiC Schottky Barrier Diodes (SBD)
- SiC MOSFETs
- SiC Junction Barrier Schottky (JBS) diodes

4.2 GaN Power Devices

- GaN High Electron Mobility Transistors (HEMTs)
- Enhancement-mode GaN transistors

These devices enable efficient power conversion across a wide voltage and frequency range.

---

5. Advantages of WBG Devices over Silicon Devices

Wide-bandgap semiconductor devices offer several advantages over conventional silicon devices:

- Reduced switching losses at high frequency
- Higher voltage blocking capability
- Smaller passive components due to high-frequency operation
- Improved system efficiency
- Higher reliability in harsh environments

These benefits significantly improve overall system performance.

6. Applications of Wide-bandgap Semiconductor Devices

6.1 Electric Vehicles

WBG devices are extensively used in EV traction inverters, onboard chargers, and DC–DC converters. They improve driving range, reduce weight, and enhance power density.

6.2 Renewable Energy Systems

In solar inverters and wind energy systems, WBG devices enable higher efficiency and compact design.

6.3 Power Supplies and Data Centers

GaN devices are widely used in high-frequency switched-mode power supplies for improved efficiency and reduced losses.

6.4 Aerospace and Defense

Due to their high-temperature and radiation tolerance, WBG devices are suitable for aerospace and military applications.

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7. Challenges and Limitations

Despite their advantages, WBG semiconductor devices face certain challenges:

- Higher manufacturing cost
- Packaging and reliability issues
- Gate driving and protection complexity
- Limited availability of standard testing methods
- Electromagnetic interference (EMI) concerns

Ongoing research aims to address these challenges.

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8. Future Trends and Research Directions

Future developments in WBG semiconductor technology include:

- Cost reduction through improved fabrication techniques
- Advanced packaging and thermal management
- Integration with intelligent control systems
- Increased adoption in mass-market applications
- Development of ultra-wide-bandgap materials such as Ga_2O_3 and diamond

These advancements will further accelerate the adoption of WBG devices.

---

9. Conclusion

Wide-bandgap semiconductor devices represent a significant advancement in power electronics technology. With superior electrical and thermal characteristics, materials such as SiC and GaN enable high-efficiency, high-power-density systems. Their growing adoption in electric vehicles, renewable energy systems, and industrial applications highlights their importance in achieving energy-efficient and sustainable technologies. Continued research and development will further enhance their performance and commercial viability.

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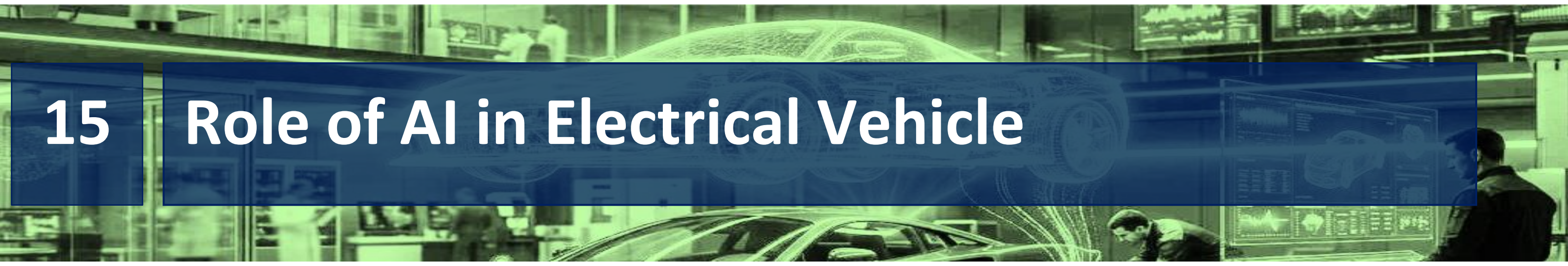

15 Role of AI in Electrical Vehicle

The integration of Artificial Intelligence (AI) into Electric Vehicles (EVs) represents a convergence of two of the most significant technological shifts of the 21st century. While the battery and motor provide the physical power, AI serves as the "digital brain" that makes these vehicles efficient, safe and viable for a mass-market future. Role of AI plays across the EV ecosystem, categorized by its primary impact areas.

---

1. Advanced Battery Management Systems (BMS)

The battery is the most expensive and critical component of an EV. AI has transformed the BMS from a simple monitoring tool into a predictive powerhouse.

State of Health (SoH) Prediction: Batteries are complex chemical systems. AI algorithms analyze real-time data on voltage, current, and temperature to predict how a battery is aging. By comparing this data against "digital twins" (virtual models of the battery), AI can adjust charging speeds to prevent degradation, potentially extending battery life by up to 25%.
Thermal Management: AI monitors heat distribution across thousands of cells. It can predict thermal runaway (potential fire hazards) before it occurs and trigger cooling systems proactively, rather than reactively.
Charging Optimization: AI identifies the fastest possible charging curve for a specific battery without causing internal damage, significantly reducing the time drivers spend at charging stations.

---

2. Eliminating Range Anxiety

Range anxiety- the fear that a vehicle will run out of power before reaching a destination—is a major barrier to EV adoption. AI addresses this through precision analytics.
Predictive Range Estimation: Unlike traditional gauges that offer a "guess-o-meter," AI-powered systems factor in elevation changes, wind speed, ambient temperature (which affects battery efficiency), and even the driver's personal habits. This provides a high-confidence range estimate that reduces driver stress.
Intelligent Trip Planning: If a driver enters a destination beyond the current range, AI automatically maps a route that includes charging stops. It doesn't just pick any charger; it selects the ones with the fastest available speeds and predicts wait times based on real-time data.

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3. Energy Efficiency and Power Electronics

AI optimizes how electricity moves from the battery to the wheels, ensuring that every kilowatt is used effectively.
Regenerative Braking Optimization: AI analyzes traffic flow and road topography to determine how much energy to recover during braking. In heavy traffic, AI can manage one-pedal driving more smoothly than a human, maximizing energy recapture.

Torque Vectoring: Electric motors can adjust power in milliseconds. AI uses this to manage torque at each individual wheel, improving traction on slippery surfaces and enhancing cornering performance far more precisely than mechanical systems in gas cars.

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4. Predictive Maintenance

EVs have fewer moving parts than internal combustion engines, but their electronic complexity is much higher. AI shifts maintenance from a "schedule-based" model to an "evidence-based" model.

Anomaly Detection: AI monitors subtle vibrations or electrical fluctuations that are invisible to humans. It can detect a failing cooling pump or a degrading power inverter months before a breakdown occurs.

Over-the-Air (OTA) Fixes: Many AI-identified issues can be fixed via software updates. The vehicle can "heal" itself while parked in the owner's garage, eliminating the need for a physical visit to a service center.

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5. Autonomous Driving and Safety

While autonomous driving exists in gas cars, it is native to the EV architecture. EVs are "software-defined vehicles," making them the ideal platform for AI pilots.

Sensor Fusion: AI processes massive amounts of data from LiDAR, Radar, and cameras to create a 360-degree map of the environment.

Emergency Response: Because electric motors respond instantly (no gear shifting or fuel combustion delay), the AI can execute evasive maneuvers or emergency braking with significantly lower latency than a human or a traditional vehicle.

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6. Smart Charging and Grid Stabilization

The role of AI extends outside the car and into the electrical grid.

Vehicle-to-Grid (V2G) Technology: When millions of EVs plug in at the same time, the grid can be overwhelmed. AI coordinates "smart charging," where cars charge only when demand is low or renewable energy (solar/wind) is at its peak.

The EV as a Battery: During peak demand or emergencies, AI can signal the car to discharge a small amount of its power back into the home or the grid, essentially turning the EV into a mobile power plant.

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7. Personalized User Experience

AI transforms the cabin into a personalized living space.

Natural Language Processing: AI-driven voice assistants allow drivers to control everything from cabin temperature to navigation without taking their eyes off the road.

Adaptive Environments: Using facial recognition, AI can identify the driver and automatically adjust seat position, mirrors, suspension stiffness, and even music playlists to match their preferences.

Conclusion

Artificial Intelligence is the catalyst that allows the electric vehicle to outperform its gasoline-powered ancestors. By solving the challenges of battery degradation, range uncertainty, and grid integration, AI is not just a feature of the EV, it is the foundational technology that makes sustainable transport a practical reality for the global population. As AI models become more sophisticated, the EV will evolve from a simple mode of transport into a highly intelligent, self-sustaining mobile device.

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Design and Implementation of IoT Based Energy Monitoring System for Smart Energy Meters

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***Abstract*—In the modern era, for optimal power utilization and to lower costs, effective energy monitoring is required. This paper presents the design and implementation of an IoT-based monitoring and visualization system for multifunction meters. A multifunction meter (Secure Make - Elite 440 model) is integrated with an IoT gateway (Teltonika Make - TRB 145 model) using RS-485 Modbus communication to measure real-time electrical parameters. The data collected and then data is sent to the cloud via Azure IoT Hub were it is stored and processed for further analysis. A web-based dashboard is developed for the visualization of real-time and historical data by which users are able to monitor energy usage efficiently. The developed system offers a real-time, user-friendly, scalable energy monitoring system, used for both residential and commercial industries. In addition to cost savings and operational efficiency, the developed system supports the Sustainable Development Framework (SDF) and is aligned with the United Nations Sustainable Development Goal 7 (Affordable and Clean Energy) as it promotes clean energy transitions and smarter energy management on the demand side. Experimental evaluation shows that the proposed system achieves near real-time performance with an average end-to-end latency of approximately 0.8 s, a maximum observed latency of about 1.3 s, zero packet loss and stable three-phase voltage measurements under continuous operation.**

***Index Terms*—Internet of Things (IoT), multifunction meter(Secure Make - Elite 440 model) , RS-485 Modbus, IoT gateway (Teltonika Make - TRB 145 model), Azure IoT Hub, Cloud platform, Real-time monitoring, Energy visualization, Web-based dashboard, Energy management, Zero packet loss, Sustainable Development, Framework (SDF), UN SDG-7.**

I. Introduction

The development of smart grid technologies and the increasing emphasis on efficient energy management has increased the demand for smart metering systems that allow for real-time data acquisition, monitoring and control of electrical parameters [1]. multifunction meters are well known to be able to help improve energy efficiency through providing accurate measurements and supporting automated data communications [2]. To provide self-reliant connectivity between smart meters and remote monitoring systems, IoT gateways are often implemented in industry. Devices such as the TRB145 LTE IOT gateway acts as an industrial communication enabler, providing features such as serial interface support and compatibility using common industrial protocols [3]. Such gateways play an important role in bridging field-level devices with cloud-based platforms. For efficient data transmission, the Message Queueing Telemetry Transport protocol (MQTT) is convenient because of its lightweight publish-subscribe architecture, which is especially suitable for constrained device networks [4]. It gives scalability to it, reduced bandwidth usage and secure communication, which makes it a preferred choice in IoT-based monitoring applications. For cloud service, platforms for example, Microsoft Azure IoT Core offers an integrated environment for device management, real-time analytics and large-scale data storage [5]. By taking advantage of these platforms, secure ingestion, visualization and processing of streaming data coming from IoT hardware, together these components, such as smart meters, IoT gateways, MQTT and cloud platforms form the backbone of modern energy monitoring systems to facilitate data-driven decision-making for both utilities and consumers.

A. Major Contributions

This work makes the following contributions:

- Design and implementation of an IoT-based real-time energy monitoring system using Modbus-enabled multifunction meter s.
- Integration of an industrial IoT gateway with secure MQTT communication for cloud transmission.
- Development of a scalable cloud architecture for real-time processing and storage of energy data.
- Implementation of a web-based dashboard for real-time visualization and analysis.
- Experimental validation of the system under practical operating conditions with low latency.

II. Literature Review

The rapid development of technologies related to energy monitoring has occurred primarily through the convergence of

IoT-enabled sensors, cloud-based data processing/visualization frameworks. This was validated through previous studies examining the application of IoT-based designs utilizing lightweight communication protocols and analytics platforms. Garcés et al. [1] developed an IoT-enabled smart electric meter that could transmit electrical parameters in real-time via the internet, enabling analysis for energy efficiency. The system used embedded metering hardware integrated with wireless communication capabilities and provided remote visualization, validating its ability to provide scalable and reliable real-time monitoring. The modernization of Electric Power and Energy Systems (EPES) is largely reliant upon the incorporation of the Internet of Things (IoT), providing both sustainability, reliability and efficiency. IoT serves as the ”nervous system” of the smart grid, providing real-time situational awareness [11]. Additionally, IoT enables utilities to utilize real-time feedback loops to enhance control functionalities and improve services delivered to customers. The vast amounts of data produced by IoT devices create challenges for centralized cloud computing, resulting in increased latency and bandwidth bottlenecks. Therefore, the current focus is on Intelligent Edge Computing, which shifts computational tasks from the center of the network to the edge [10], creating a more decentralized model of data processing. This approach supports real-time decision making and reduces data transmission costs to support the demands of smart grid applications. Forsström and Jennehag [9] demonstrated the use of OPC-UA with Microsoft Azure IoT Hub in Industrial IoT (IIoT) environments, resulting in reliable and low-latency communication between the two systems. The authors' findings supported the use of Azure IoT Hub for large-scale, institutionally deployed applications and therefore support the cloud-based platform selection for the proposed system. An IoT-based predictive modeling is a significant way to improve how buildings manage their own energy levels; research has shown that building-level electric energy consumption can be predicted with high accuracy through establishing relationships between net consumption and environmental factors, such as ambient temperature and the state of occupancy. Recurrent Neural Network models(RNN) are very effective at predicting near-future loads for HVAC units and lighting panels, allowing systems to respond to changing energy demands to minimize waste and reduce greenhouse gas emissions.[8]. The Secure Elite 440 series datasheet was used to determine the electrical specifications, register map and Modbus configurations to obtain the necessary data regarding voltage, current, power factor and energy data for both utility (MSEDCL) and diesel generator (DG) sources. The Teltonika TRB145 User Manual[3] allowed us to configure the RS-485 communication protocol, perform Modbus Master Polling, forward the data via MQTT and establish 4G LTE connectivity. Lastly, the Modbus Application Protocol Specification[6] provided a framework for reliable RS-485 communications, specifying the frame structure, function code, register address space and error handling mechanisms.

A. *Research gap*

Recent designs for IoT-based energy monitoring systems mainly emphasize data acquisition and visualizations, yet few ensure valid real-time operation, scalable cloud connectivity and practical validations for industrial low-tension environments. Many projects fail to ensure continuous monitoring with low latency or fail to incorporate secure communication protocols for industrial implementations. Moreover, there are very few attempts to integrate seamless connectivity solutions for cloud systems for Modbus-based multifunction metering, along with lightweight messaging protocols for real-time analysis and visualizations. This emphasizes the need for a scalable, secure and robust IoT-based energy monitoring system, which can enable real-time data acquisition, cloud processing and visualizations, thereby being addressed by this proposed solution.

III. System Architecture

The system architecture of the proposed system is as shown in Fig.1, the system offers a precise and distributed measurement of energy in a low-tension electrical system. The platform combines industrial-grade metering hardware with a cloud-based platform, which is a highly scalable platform for real-time monitoring of data and energy management. Although it is well-suited for domestic estates, it is mainly used in LT industrial applications where consumption data granularity and the efficiency of operation is crucial. The system architecture is divided into two functional blocks, which consist Data acquisition and monitoring. Data acquisition involves collecting raw data from field devices and transmitting it to be analyzed in real-time.

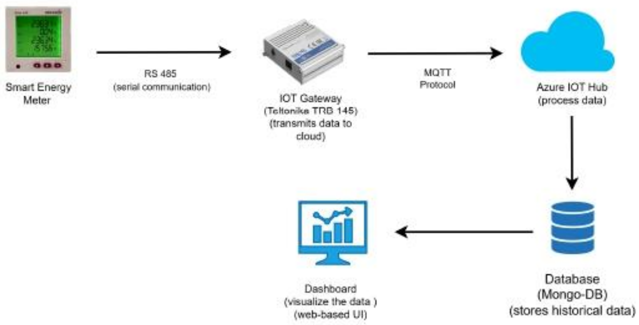

Fig. 1. System architecture of the IoT-based energy monitoring system.

A. *RS-485 communication*

The most recent multifunction meters support both RS-485 communication and onboard IP connectivity, allowing for easy connectivity to systems and new network infrastructures. RS-485 communication provides a maximum of 32 drivers and 32 receivers with a maximum data rate of 10 Mbps in differential (balanced) mode. The two-wire half-duplex configuration is the most conventional and is widely used in meter networks due to its stability [6]. The system incorporates a Secure Elite

440 energy meter that communicates using an RS-485 Modbus protocol to read electrical parameters, such as voltage, current, power, and energy consumption [7].
RS-485 enables long-distance communication with multiple slave devices on a single bus, using differential positive and negative lines. It operates on a request–response mechanism, where the gateway queries specific registers and the meter replies with data.

B. Gateway Configuration

The Teltonika TRB145 was set up as a Modbus serial master, aligned with the meter parameters (Slave ID, baud rate, parity, stop bits). The essential registers for voltage, current and power were polled to ensure the accurate and timely acquisition of the electrical parameters in real-time.

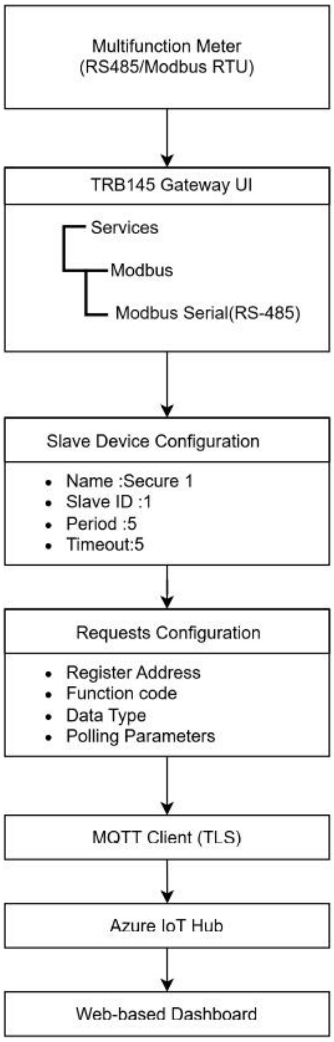

Fig. 2. Flowchart of MQTT-based communication using IoT gateway.

C. MQTT Configuration (TRB145 to Cloud Broker)

The TRB145 gateway was configured to function as an MQTT client for the Azure IoT Hub. This allowed secure data transfer over TLS using Port 8883. Device authentication relied on SAS tokens that were generated automatically through Teltonika's Azure IoT integration package. This approach eliminated the need for manual certificate handling and made token renewal seamless. MQTT settings included the broker endpoint, the publish topic and the Quality of Service level (QoS 1, which ensures at least once delivery). These settings met the IoT Hub requirements. This setup enables TRB145 to consistently publish real-time Modbus register data such as voltage, current and power, directly to the cloud for further analysis and monitoring.

D. Modbus

Modbus is a binary serial communication protocol that is used for real-time data acquisition because of its efficiency and structured master–slave mechanism. The TRB145 gateway functioned as the Modbus master, issuing register queries, while the energy meter operated as the slave, providing the corresponding electrical parameter values. Azure IoT Explorer was utilized to validate data flow by subscribing to the designated topic, verifying real-time payloads with correct time stamping and format. Device-to-cloud message status, transmission frequency and connection activity were further monitored through Azure IoT Hub metrics and logs. Azure IoT Hub was set up to receive telemetry from the TRB145. A device identity and connection string were created. The Teltonika package handled SAS token authentication automatically. Data routing was directed to MongoDB Atlas for storage and Time Series Insights for visualization. Native monitoring services in Azure were used to track message flow, connection stability and device health in real-time.

E. User interface

A real-time smart meter dashboard is used to visualize and analyze telemetry collected through the Teltonika TRB145 gateway. The system uses a scalable Node.js backend, with MQTT/WebSocket streams allowing low-latency data transfer to the visualization layer. The dashboard offers interactive time-series plots of voltage, current, active/reactive power, frequency, power factor and cumulative energy. Charts are backed by MongoDB as the time-series database. Users can zoom into intervals, set a custom range and compare trends with stacked area and bar charts for daily or weekly analytics. A heatmap module shows anomalies by encoding parameter intensity over time. This helps quickly detect undervoltage windows, load spikes, or over-current events.
These plots update in near real-time through backend streams. Additionally, tabular views record each incoming data packet with timestamps, as well as filter and sort functions. A system summary panel which includes energy consumption, peak/average load, power quality and uptime across devices or sites, supporting operational decisions like load balancing and efficiency optimization. The alert module enforces threshold-based fault detection (e.g., overvoltage/undervoltage, overcurrent, device disconnection). Notifications appear as graphical warnings on the dashboard and are escalated via SMS, with

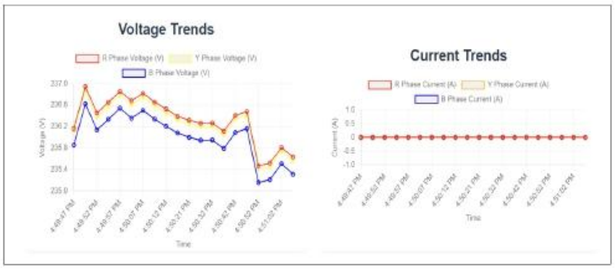

Fig. 3. Web-based dashboard for visualization of voltage and current.

events logged and tracked until acknowledged. By combining real-time analytics, anomaly detection, automated reporting and proactive alerts, the dashboard evolves from a passive monitoring tool into a decision-support system aligned with contemporary IoT energy management frameworks.

IV. Results

The smart energy monitoring and visualization system is developed in well-defined phases, with an end-to-end proof of concept. The system architecture combines a multifunction meter, an industrial IoT gateway and a cloud-based monitoring platform to obtain real-time acquisition, secure communication and web-based visualization of electrical parameters. During the first phase, the hardware configuration was put in place, comprising a Modbus RTU-capable smart meter coupled through RS-485 to the TRB145 LTE industrial gateway.

TABLE I
Sample Of Voltage Measurements Stored in the Cloud Database

Timestamp	Voltage R (V)	Voltage Y (V)	Voltage B (V)
27-09-2025 17:10:54	227.90	230.13	229.03
27-09-2025 17:10:49	228.43	230.41	229.51
27-09-2025 17:10:45	228.30	230.05	229.40
27-09-2025 17:10:39	228.40	229.81	229.77
27-09-2025 17:10:34	228.12	229.93	229.15
27-09-2025 17:10:29	227.80	229.80	228.87

The gateway was set up as a Modbus master to read parameters like voltage, current, power and power factor at regular intervals. Careful mapping of Modbus register addresses ensured that all parameters were correctly read from the meter under run-time conditions.

After successful telemetry collection at the local endpoint, the gateway's MQTT client was set to publish the collected telemetry. The publish–subscribe pattern was developed using multiple brokers and finalized with the Microsoft Azure IoT Hub due to its reliable integration and support for device authentication, as well as protocol translation. The TRB145 gateway sent reliable JSON-structured payloads, which were received in the Azure IoT environment with near-zero packet loss and very low latency. End-to-end testing ensured that changes in electrical load, i.e., turning appliances on or off, were immediately reflected in the arriving telemetry.

Application-level processing of the ingested data was carried out and routed to a visualization layer with no permanent cloud storage.

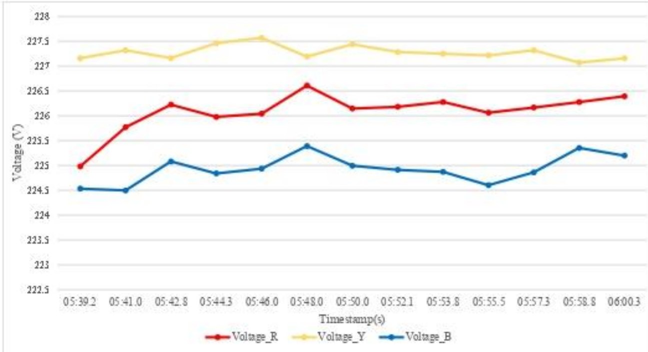

Fig. 4. Three-phase voltage variation obtained from the system

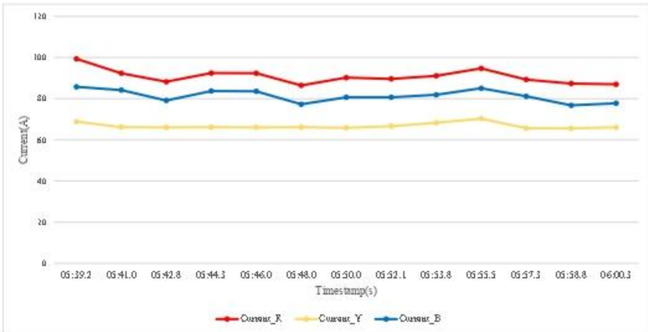

Fig. 5. Three-phase current variation obtained from the system

A web-based dashboard was implemented within the Azure platform, intended to display real-time energy parameters as numbers and graphs. The dashboard was updated at short, frequent intervals, allowing for monitoring of dynamic consumption changes. The interface was tested in simulated and real operating conditions and the results validated its responsiveness, accuracy and ease of interpretation. In total, the system effectively proved its ability to make measurements at the meter level, send them through an IoT gateway using MQTT and render them in real-time on a cloud-based dashboard. Each component of the architecture—hardware acquisition, gateway communication, protocol handling, cloud integration and visualization was individually and collectively validated and confirmed the stability and efficiency of the end-to-end solution.

The IoT energy monitoring system would be "have been experimentally evaluated to validate data acquisition in real communication reliability and the use of the cloud for visualization Industrial cellular Gateway.

The review was centered on the end-to-end telemetry transmission from the multifunction meter to the web-based dashboard. When tested, physical variables of the electrical process were acquired from the multifunction meter employing the Modbus communication protocol. The Teltonika TRB145 gateway was set to poll the meter at a fixed transmission interval of 5 seconds and publish telemetry sensor data to the cloud platform through a cellular network using MQTT. With timestamped records that verify this, telemetry packets were received with a periodicity very close to the rate of publication as specified. The rate of the observed inter-message interval varied between 4 s and 6 s, relating to a timing delay of ±1 s around the nominal value. This variation is due to cellular network latency and MQTT broker scheduling.

TABLE II
SYSTEM PERFORMANCE METRICS

Metric	Observed Value	Remarks
Data publish interval	4–6 s	+1 s jitter due to cellular and cloud scheduling
Average end-to-end latency	∼0.8 s	Meter → Gateway → Cloud → Dashboard
Maximum observed latency	∼1.3 s	During peak network activity
Timing jitter	±1 s	Acceptable for near real-time monitoring
Packet loss rate	0%	Continuous data stream observed
Parameters monitored	8	Voltage (R,Y,B), Current (R,Y,B), Power Factor, Active Power
Communication medium	Cellular (LTE)	Eliminates Wi-Fi range limitations
Operation duration	>30 minutes (continuous)	No communication failure observed
Message frequency configurability	Runtime configurable	No firmware modification required

The protocol stack supports both UDP and cloud-level timestamp resolution, which are inherent properties of characteristics of wide-area IoT communication systems. Despite minute differences in timing, the results showed zero packet loss, while at the same time ensuring constant data flow. The test duration voltages measured: R, Y and B phases remained stable and within normal operating parameters, confirming the correct Modbus register mapping and data integrity. The changes that occurred in the electrical load were immediately conveyed to the interface, including the creation of a dashboard capability. The recorded average latency of about 0.8s with a maximum latency of 1.3s, which shows that the proposed architecture is is well-designed for real-time energy monitoring applications where sub-second response times are desired, but the constraints for hard real-time systems are not compulsory. In comparison to the Wi-Fi-based solution for the Internet of Things, such as systems, in terms of deployment capabilities that are enhanced in the proposed architecture, which increases flexibility for users through cellular connectivity, removing the constraints of limitations related to local wireless communication networks. In addition, the configurable message transmission interval at runtime enables adaptive control of the data ingestion rate to optimize cloud resource utilization without firmware modification. Conclusively, the experiments show that the correctness of the designed system provides a stable, scalable and reliable solution for real-time energy consumption monitoring utilizing industrial-grade hardware and cloud services, with the ability to monitor various electrical parameters and extend the system for future analytics applications.

V. CONCLUSION

This system demonstrates the implementation of a smart energy monitoring and visualization system with a Modbus-based multifunction meter, an industrial IoT gateway, and a cloud-based Dashboard platform. This system has demonstrated through its results and is capable of retrieving live electrical parameter information from the multifunction meter and securely sending this information as MQTT messages to the cloud-based dashboard for display. The IOT gateway provided a secure path to send information from the cloud-based service to the smart energy meter and the Azure IoT hub provided a reliable platform for the processing of the received data, for authenticating the devices and for developing the user interfaces of the dashboards. The system provided low latency and minimal loss of data and therefore would be suitable for use in real time monitoring applications. The recorded average latency of about 0.8s with a maximum latency of 1.3s, which shows that the proposed architecture is is well-designed for real-time monitoring along with zero packet loss and stable three-phase voltage measurements under continuous operation. This system is an example of a concept for remote and interactive monitoring of energy usage and provides information about how real-time energy monitoring using IoT-based technologies can increase efficiency, which makes a better choice for decision-making in energy management. Future development of this project could include predictive analysis, automatic notification, load forecasting and integration of renewable energy sources. Therefore, the potential exists for this project to develop into a more integrated platform that will be able to support the needs of smart grids and renewable energy practices.

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Research paper

An Analysis of cyber threats in distributed energy power networks

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Abstract

The power demand has increased dramatically in recent years. Conventional power generation provides about 80% of the world's energy. Distribution networks are essential to the electrical grid system because they link consumers to the transmission system. Distribution networks require careful planning since they are vast and complex. Congestion in the distribution network quickly affects the network's voltage profile as power demand increases, leading to power outages and delayed power delivery. Since Active Distribution Networks (ADNs) are more vulnerable to cyberattacks due to their integration with cutting-edge communication and control technologies, detecting these attacks is a critical problem in modern power systems. The possible cyberattacks on power systems are covered in this paper. To identify the possible, cyberattack, an IEEE-15 bus system with Cyber-Physical Layering (CPL) is suggested. Cyberattack detection systems defend ADNs against assaults including data alteration, illegal access, and service denial by utilizing machine learning, anomaly detection, and real-time monitoring. Using machine learning techniques, such as DT, NNN, and SVM, cyberattack detection is also carried out on modified IEEE-15 bus systems and CPL-based IEEE-15 buses. Additionally, a comparative analysis of the methods for cyberattack detection is conducted.
The paper discusses how advanced communication and control systems in active distribution networks (ADNs) face heightened cyber risks from both traditional threats like DoS and FDI attacks and emerging quantum computing-based attacks. It highlights vulnerabilities across CPL layers and recommends AI/ML anomaly detection, quantum-safe cryptography, and robust network designs for future resilience.

Keywords*: Cyberattacks, Vulnerabilities, Microgrid, Distributed System, Denial-of-Service, Communication, Algorithm.*

1. Introduction

21st century electric power structures have seen dramatic change because of progresses in digital technology, automation, and connectivity. Modern cyber power systems usher in a new era of extraordinary efficiency, reliability, and durability by fusing traditional energy infrastructure with cutting-edge communication and information technology. From production and transmission to distribution and consumption, every phase of the energy system makes use of ICT-enabled machinery, sensors, and software platforms. Their goals are to enhance grid resilience, facilitate better operations, and enable more informed decision-making. Furthermore, modern cyber power systems employ cutting-edge automation and control technologies to improve energy distribution efficiency and preserve a real-time supply-demand balance. Demand-side management programs, intelligent control algorithms, and distributed electrical resources enable real-time adjustments to grid properties, including voltage levels and electricity flow, to preserve stability and dependability in a variety of operating scenarios. An essential part of today's intelligent power system is a cyber-physical microgrid. Its goal is to provide safe and efficient electricity distribution while upholding a high standard of environmental responsibility worldwide. The CPL microgrid achieves optimal operation by implementing distributed control of electrical elements using modern processing and communication technologies. The microgrid's control unit manages regulated loads and a variety of Distributed Energy Resources (DERs) to deliver reliable, reasonably priced power with minimal environmental impact. A typical structured control system with three levels that operate on various time scales to achieve control objectives is shown in Figure 1.
All the micro-generating modules of a CPL Microgrid provide DC power. To provide AC power to the loads, inverter circuits are necessary. Communication agents with routers, links, local controllers, and advanced algorithms make up the cyber layer. Its goal is to address the various problems that microgrid operators and consumers face. The CPM may operate in single mode due to planned scheduling or an unforeseen attack.

Because of the low fault current in inverter-based CPM, it is discovered that traditional protective relays need to be enhanced to better protect the system. Faults that are closely associated with the line and ground are the most observed. For a fault mitigation model to work well, it needs an efficient fault detection technique that incorporates algorithms for accurately categorizing and recognizing defects. This method, which entails classifying the flaws and putting in place an appropriate mitigation strategy to decrease the time and cost needed for restoration, increases the credibility of the overall protection process.

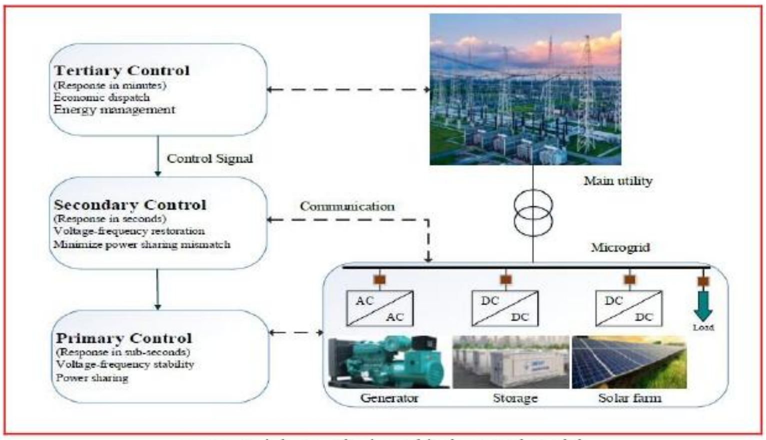

Fig. 1: Triple-Level Hierarchical Control Model

1.1 Cyber Threats in Distribution Systems

The distribution system is more vulnerable because of serious cybersecurity threats. Threats to exploit these vulnerabilities for assaults and disrupt the distribution system's functionality are growing significantly. The distribution system's automation and communication technologies have advanced, giving attackers the potential to alter or interfere with the ICS and cause disruptions. Additionally, more DERs are being integrated, which means that the grid is receiving more power than it needs. Because these DERs are configured to monitor and regulate the system, they increase the grid's susceptibility to cyberattacks and possible outages. To disrupt the system or induce a blackout, attackers employ a variety of attack techniques to compromise the distribution network.
The integrated nature of microgrids and the internet connections they are connected to make them extremely susceptible to cyberattacks. Information-sharing devices and intelligent gadgets may be vulnerable to malicious assaults that take advantage of system flaws due to their integration and the lack of thorough security standards. The volume of data flow is directly impacted by the scalability of smart grid technology since it raises the demands on computation and transmission. Figure 2 illustrates the various forms of cyberattacks on power systems.

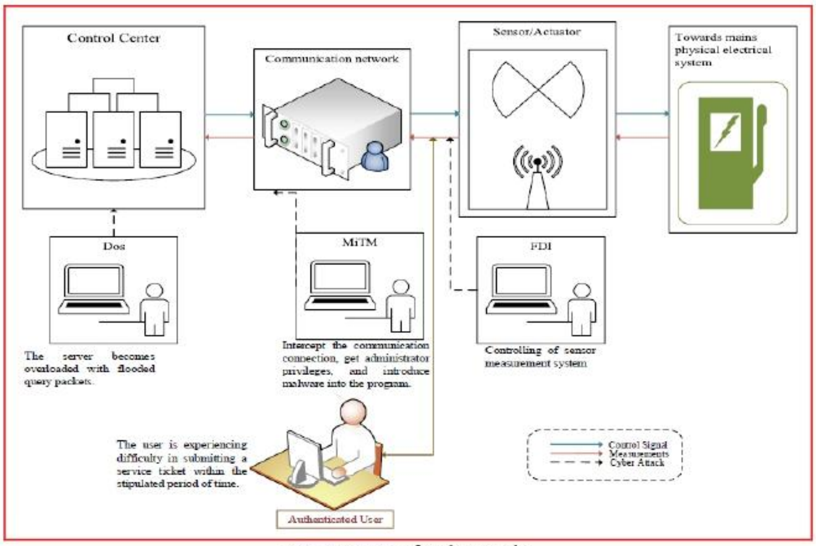

Fig. 2: Types of Cyberattacks

1.2 Denial of Services

A cyberattack that prevents an authorized user from interacting with a network is called a denial-of-service (DoS) attack. The attackers of this cyberattack can manipulate a small number of devices to cause harm to the electrical control system, even though they do not have full access to it. The goal of a DoS attack is to render a system unusable by flooding it with requests, denying access to authorized users. To prevent operators from responding to valid requests, the attackers use several customized distributed systems to send a substantial number of undesired queries to the target level. Demands and congestion overwhelm the system infrastructure, making it unable to respond to valid clients or processes. While these attacks are frequently associated with the disruption of websites or online services, they can also pose a major threat to critical infrastructure, including power grids. Network jamming is another form of denial-of-service attack. Since microgrid control is predicated on information sharing, DoS attacks pose a significant threat to their functionality. These types of assaults can be carried out without knowledge of the microgrid setups or the necessary skills to alter orders and measurements.

1.3 False Data Injection

The careful introduction of false or falsified information through the control networks or sensors in charge of keeping an eye on and managing the operation of the power grid is known as a False Data Injection (FDI) cyberattack in electrical systems. These attacks have the potential to have serious consequences, such as bodily harm, equipment malfunction, and power outages.
Malicious actors compromise electrical system sensors, such as voltage and current sensors, and then alter the data that is relayed. This is known as FDI. Adversaries can use fake data to manipulate such metrics and divert control systems from making appropriate judgments. In power systems, state estimate is crucial for ensuring system stability and dependability. FDI attacks have the potential to corrupt the data used for state estimation, leading to inaccurate assessments of the system's health. This could result in control systems making mistakes, such as failing to detect defects or making insufficient generation adjustments.
A sequence of failures could occur if incorrect data is injected into the electrical system and spreads throughout the network. Because FDI assaults often try to mimic typical system activity, they might be challenging to detect. To maintain credibility, attackers may carefully craft the data they introduce, making it challenging for system management to discern between accurate and fraudulent information. Attacks of this type alter data and may compromise system stability and reliability by exploiting flaws in the software, hardware, or communication regulations used in power electrical grids. Inaccurate state estimation and synchronization loss could emerge from the outcome, which would have a detrimental effect on economic dispatch and the supply of electricity to critical loads. This kind of erroneous data injection could harm the communication network, controller hardware, etc.

1.4 Reply Attack

In an electrical system, a reply-type cyberattack is when an adversary gains access to the system with the goal of altering data or interfering with its operation. Hackers may use hardware or software flaws to enter control systems without authorization during these attacks. This allows them to alter vital infrastructure or add false information to sensor readings. These kinds of attacks have the potential to seriously disrupt the economy, public safety, and the reliability of the electricity supply. Implementing stringent safety measures, such as regular system audits, establishing intrusion detection systems, and educating staff to recognize and promptly address any threats, is essential to preventing reply-type cyberattacks in power systems. Furthermore, the separation of networks and the use of encrypted communication protocols can both successfully limit the scope of assaults and lessen their effects.

1.5 Main-in-the-Middle Attack

An unauthorized third party can intercept and perhaps alter information between two authorized organizations within a power network between two legitimate devices, listen in on the discussion, or provide fake information or directives. This type of cyberattack is called a Man-in-the-Middle (MitM). Critical power system segments may also be the target of these attacks to gather information about communication with control center staff that may be utilized to launch more attacks. The attacker might disrupt the entire system by listening in on all requests and data sent between these actual devices.
Devices 1 and 2 are directly connected to a communication network in Figure 3, which illustrates a structural representation of MITM. A new connection is created by recording the two devices' conversation and sharing erroneous data across this intermediary channel.

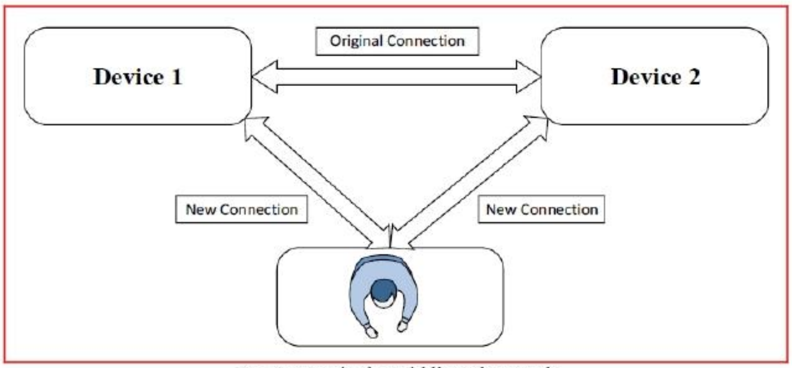

Fig. 3: Man in the Middle Cyberattack

1.6 Emerging Threats in the Cyber-Physical Layer of Active Distribution Networks:

The integration of advanced communication and control systems in active distribution networks (ADNs) has exposed them to increasingly sophisticated cyberattacks. While traditional threats like Denial-of-Service (DoS) and False Data Injection (FDI) attacks already compromise the reliability and stability of the power grid, emerging threats such as quantum computing-based attacks present an even greater risk. Quantum computing, with its ability to break traditional cryptographic algorithms rapidly, can potentially compromise data integrity and confidentiality in the communication layers of ADNs. This creates vulnerabilities in the CPL's layered structure, where secure data transmission and real-time monitoring are crucial.
The file highlights these vulnerabilities in the sensing, network, data processing, and application layers of CPL-based systems, making them susceptible to manipulations such as malicious data injections, man-in-the-middle attacks, and tampering of operational commands. As quantum computing evolves, it could break the encryption and authentication protocols that protect communication between sensors, controllers, and actuators, making quantum-based attacks a looming threat to the grid's stability and security.
Mitigating these emerging threats requires not only robust anomaly detection techniques using AI/ML, as explored in the document, but also the adoption of quantum-safe cryptography and resilient network designs that account for these advanced, future threats.

2. Techniques and Conceptualization of Problems

The distortion thereby induced by a malfunction or breach in one of the generators can be extended throughout the other generators by a synchronized control system that can put the entire system at risk. Finding anomalies in the control systems of the cyber-physical microgrid is still a challenge. A few disadvantages of traditional methods include a longer training period, hyper-parameter sensitivity, the possibility of data loss, and overfitting due to the discrete features of the transformation. These problems make it difficult to detect attacks in cyber-physical systems using traditional methods. Therefore, after the difficulties are identified, the goals are defined. Notable contributions consist of:

a. The goal is to develop an ideal machine learning algorithm that can reliably distinguish between a cyberattack and a fault in the cyber physics layer CPL-based IEEE-15 bus benchmark distribution system and the CPL-modified IEEE-15 bus system.
b. to identify the cyber-physical anomalies by introducing machine learning classifiers to the suggested SIFI model.
c. To create a method for employing DoS and FDI to identify cyberattacks.
d. Machine learning methods are compared to determine whether the anomaly is a cyberattack or a problem so that the performance of the constructed system can be evaluated.

3. Proposed System

The Modified IEEE-15 bus system, and the CPL-based IEEE-15 bus benchmark are employed in this research work. Both systems, as depicted in Figure 4, consist of two layers: the cyber layer and the physical layer.

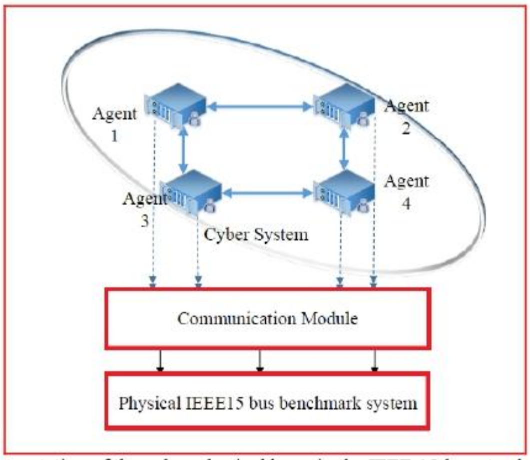

Fig. 4: Schematic representation of the cyber-physical layer in the IEEE 15-bus standard benchmark system.

The original IEEE-15 distribution system or its updated version, which is linked to the cyber layer, is the physical layer. Over a small network, the cyber layer makes it easier for physical components to communicate with one another. To provide the standard centralized secondary control, all the DGs must be connected to the central controller via an effective network. The cyber layer uses other algebraic variables and iterative computing to quantify cyber state variables. The state estimation unit's sensors provide precise real-time reading estimates, which are then sent to the processing unit. The computer unit uses a network connection to provide the estimated values to the controllers after processing the data.

The application, data processing, network, and sensing layers are the four distinct levels that comprise the structure of the cyber-physical layer. The first layer, referred to as the sensing layer, is composed of sensors and actuators connected to devices that collect and send physical or environmental data across the network. The second layer, referred to as the network layer, includes the data collecting system and the internet/network gateway. The data acquisition system gathers and combines data by converting analog data from sensors into digital format and transmitting it through an internet gateway. The data processing layer is the third layer. Prior to being transmitted to the data center, the data is pre-processed and examined in this layer. Applications for control and surveillance at the data center are used to access the data. In data centers or cloud environments, data management and storage are handled by the fourth application layer. End users then access and use this data for a variety of purposes.

This innovation improves skills in several applications. Using sensors, smart meters, communicative circuit breakers, and other intelligent electrical devices, the CPL microgrid uses a software interface to make the transition between physical and electrical distribution systems easier. With the help of the data provided, they can provide strong analytical capabilities. Critical operational technologies can now be operated and communicated with remotely, even at faraway locations, thanks to the use of CPL in distribution networks.

4. Attacks in the CPL Network

Two kinds of anomalies are taken into consideration in the modified IEEE-15 bus physical system and the cyber-physical IEEE-15 bus benchmark. The DoS at the bus node is thought to be the cause of the initial abnormality. The disconnection of network-connected resources is regarded as another FDI attack. The agent node-based IEEE-15 bus system, where the planned cyberattack is located, is depicted in Figure 5.

Intentionally adding false information to a network connection is known as malicious data injection. The attackers usually try to degrade the decision-making ability of the controller by injecting faulty data into the data stream of the cyber-physical layer. By carrying out phony data injections or transmitting misleading data to the microgrid carriers, hackers try to cause load shedding and needless tripping by increasing the reported electricity consumption to the electrical grid operator. The system controller may be alerted to a lagging power factor when a malicious risk exists. The cyber-physical layer operates at a leading power factor because of the controller's inclusion of negative kVARs to stabilize the system's PF at unity. As a result, this dominant power factor may raise the voltage level within the secondary distribution system, which could harm household appliances.

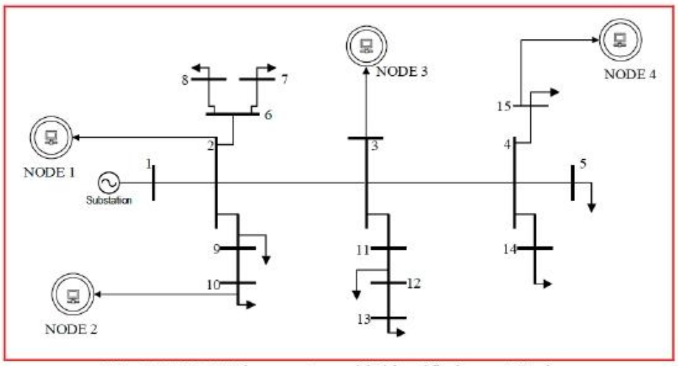

Fig. 5: IEEE-15 bus system with identified agent Nodes.

When people purposefully underreport their power usage to the operator to benefit financially by lowering their billing amount, this is known as electricity theft. Through obstruction or delay of the network connection, an intruder can make sure the operator doesn't notice changes in the load. By overloading the communication network with requests, the DoS attack takes advantage of flaws in the system and prevents the targeted components from operating as intended. Consequently, the server or communication network is unable to function effectively. A competent intrusion and fault detection system is therefore necessary.

5. Machine Learning-Based Analysis of Cyberattacks

The identification of cyberattacks or defects in CPL-based IEEE-15 and customized IEEE-15 bus systems is a good fit for machine learning methods. The cyber-physical layer module's defects and cyberattacks are found using an intelligent cyberattack and fault detection mechanism. To precisely ascertain the system's current state, the proposed method incorporates DT, NNN, and SVM classifiers. This involves determining whether the electrical distribution network is experiencing a real-time malfunction or a cyber-attack.

A cyberattack detection mechanism for the IEEE-15 bus benchmark and the updated IEEE-15 bus network system is depicted in Figure 6. For 60K samples, a database of voltage and current for symmetrical and asymmetrical faults is created. A unique categorization value is used to further classify the distribution network's defective and non-faulted statuses. The network is trained using machine learning classifiers, such as DT, NNN, and SVM, utilizing this database. Attacks of various stages, such as DoS and FDI at any node, are added in the very next step.

The distribution network's current state is made clear by interpreting this injected data as testing data. By altering sample values utilizing their multiplier changes in the original values, data manipulation is achieved. Disconnecting the different buses from their nodes also creates modified data utilizing the IEEE-15 bus. The machine learning classifier uses this data to train a network. The system is deemed to be in a real-time fault state if an attack is discovered to match the faulty data, or it is determined that the system is under cyber danger if no match is found. The modified IEEE-15 bus system and the CPL-based IEEE-15 bus benchmark both identify the cyber hazard of activity. The machine learning approach's results greatly aid in managing the distinction between an electrical distribution network outage and a cyberattack.

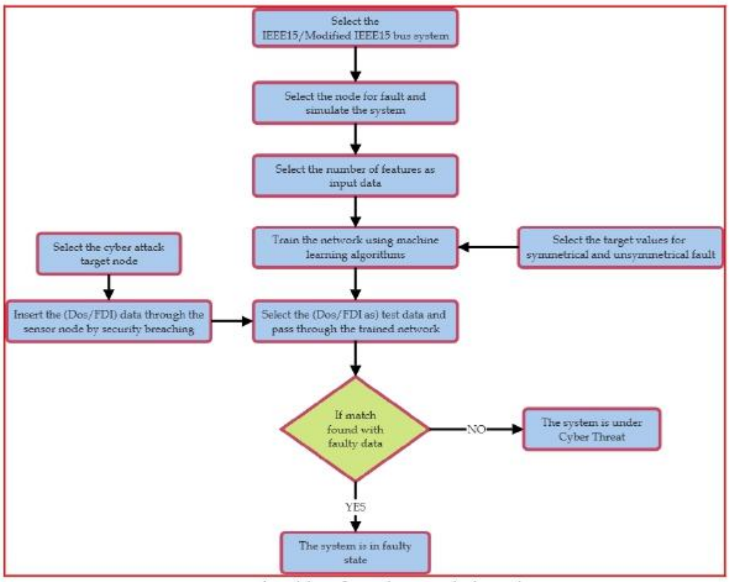

Fig. 6: Algorithm for cyberattack detection

6. Results

The CPL-based IEEE15 bus systems are subjected to performance analysis of cyberattacks and fault detection utilizing machine learning methods, such as DT, NNN, and SVM, to determine whether the system is experiencing a cyberattack or a malfunction. Two forms of cyberattacks—DoS and FDI—are suggested at various system nodes in the proposed study. The ML algorithms are thought to use the 3Ø Voltages and Currents as input. With the help of gathered data samples, the machine learning algorithms are trained and verified under no-fault, symmetrical, and unsymmetrical fault circumstances. To distinguish between a cyberattack and the existence of flaws, distinct target values are set.

The DoS and FDI attacks are proposed at the node of the IEEE15 bus network based on CPL to pick the cyberattack datasets. Both the DoS and FDI cyberattacks disrupted the sensor node and the real database. Until the problem is fixed, the network collapses because of these disturbances, which act as a network system breakdown. As illustrated in Figure 7, L-L-G faults are indicated by positions 4, 5, and 6 in the confusion matrix, while L-G fault validation is represented by places 1, 2, and 3. While the matrix 10 component suggests an L-L-L-G fault, positions 7, 8, and 9 imply an L-L fault. The DT network takes 13.14 seconds to train and has a validation error rate of 20.4%. The DT classifier maintains a validation error rate of 20.6% while achieving a validation accuracy of 79.56%. Overall, the SVM classifier has a 90.8% validation accuracy, whereas the NNN classifier has an 89.1% validation accuracy.

		Predicted Class										TPR	FNR
		1	2	3	4	5	6	7	8	9	10		
True Class	1	91.82	0.40		1.11	0.52	0.00	0.90	0.60	4.80		91.82	08.33
	2	0.81	93.28		0.40	3.12	0.10	1.46	0.10	0.90		93.28	06.89
	3	1.12	0.40	89.21	0.30	1.50	4.10	0.60	2.40	0.70		89.21	11.12
	4	0.00	0.10		94.00	1.10		5.30			0.00	94.00	06.50
	5	0.00				89.88	1.70		5.20		3.00	89.88	09.90
	6	0.00			0.50	0.60	93.52			3.50	1.90	93.52	06.50
	7	0.00	0.10	0.00	3.83	1.50		94.25	0.40	0.40	0.20	94.25	06.43
	8	0.00		1.43		12.81	0.80		82.15		1.90	82.15	16.94
	9	0.82	0.63	0.00	0.20	0.90	6.20		0.10	88.78	1.40	88.78	10.25
	10	0.00				5.80	0.20				94.68	94.68	06.00

Fig. 7: Validation matrix DT classifier

Figure 8 shows the validation matrix of SVM with an error rate of 9.2%

		Predicted Class										TPR	FNR
		1	2	3	4	5	6	7	8	9	10		
True Class	1	100.00										100.00	00.00
	2	0.00	100.00									100.00	00.00
	3	0.00		100.00								100.00	00.00
	4	0.00			100.00							100.00	00.00
	5	0.00				100.00						100.00	00.00
	6	0.00					100.00					100.00	00.00
	7	0.00						100.00				100.00	00.00
	8	0.00		0.12					100.00			100.00	00.12
	9	0.00								100.00		100.00	00.00
	10	0.00									100.00	100.00	00.00

Fig. 8: Validation matrix of SVM

The test data or the altered cyberattack data is run through the trained network following network validation. For both symmetrical and unsymmetrical defects, a test confusion matrix is seen. The confusion matrix in Figure 9 illustrates how the DT classifier predicts fault categorization during a cyberattack.

		Predicted Class												TPR	FNR
		0	1	2	3	4	5	6	7	8	9	10	11		
	0	74.10	1.62	24.3										74.10	24.30
True Class	1		100.00											100.00	
	2		0.41	99.49										99.49	00.41
	3		0.41	17.43						82.16					100.00
	4					100.00								100.00	
	5		0.41				82.05						17.59	82.05	18.00
	6					15.24		84.82						84.82	15.24
	7		0.41						99.61					99.61	00.41
	8		0.41				74.20			20.81			4.83	20.81	79.44
	9					15.24					84.91			84.91	15.24
	10		0.41										99.59		100.00
	11		0.41										99.60	99.60	00.41

Fig. 9: Test Confusion result matrix DT classifier

The classification rate of cyberattacks using the fault data is known as the true positive rate, or TPR. The fact that DT categorizes the cyberattack data as fault data is shown in the confusion matrix. Better accuracy in classifying cyberattacks is predicted by the false negative rate (FNR). The accuracy of cyberattack detection is thus represented by the overall misclassification rate.

The DT classifier demonstrates a 70.4% classification rate for cyber data as a fault. For the SVM and NNN, similar findings have been made. The test confusion matrix derived from SVM is shown in Figure 10. Figure 10 displays the classification characteristics from SVM, with the lowest classification range of 9.9% for cyberattacks from fault data. In the active distribution network, the improved misclassification findings demonstrate accurate prediction of cyberattacks. With a 90.1% success rate, SVM is shown to be the superior cyberattack classifier in this case.

		Predicted Class												TPR	FNR
		0	1	2	3	4	5	6	7	8	9	10	11		
True Class	0		100.00												100.00
	1		100.00											100.00	
	2		100.00												100.00
	3		84.77					15.23							100.00
	4		100.00												100.00
	5		87.86										12.00		99.86
	6		100.00												100.00
	7		100.00												100.00
	8		92.42										7.58		100.00
	9		100.00												100.00
	10		80.82									0.42	18.86	0.42	99.68
	11		80.82									0.42	18.86	18.86	81.24

Fig. 10: Test Confusion result matrix using SVM

Case study: Denial of Service

In the first scenario, the CPL-based IEEE-15 bus system's Node 2 is the target of the DoS cyberattack. When an unequal load is linked as a real-time request, the attack is suggested to inject data into the system, causing the system to enter a failure or breakdown condition. DG-based modified IEEE-15 bus systems are believed to have the same observation. The 3-phase voltage and current exhibit a more subtle variance in this observation. This data is fed into the trained network classifier and is regarded as testing data.

The symmetrical faults data, where the DoS threat has been categorized in the IEEE-15 bus radial distribution network, is displayed in Figures 11 and 12. The cyberattack had the lowest classification value of 58.5% for L-L-L fault situations and 19.5% for L-L-L-G fault conditions according to the DT classifier. NNN classifies the DoS assault with an accuracy of 62% and 54.4%, respectively, in the case of symmetrical defects. With a maximum rating of 99.6% and 100%, the SVM similarly categorized the incident as the same defect.

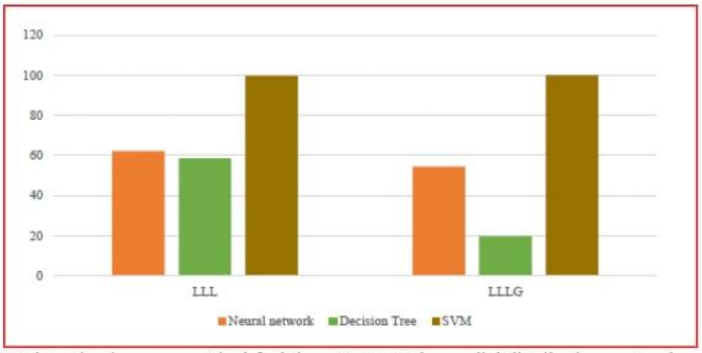

Fig. 11: DoS detection in a symmetrical fault in an IEEE-15 bus radial distribution system based on CPL

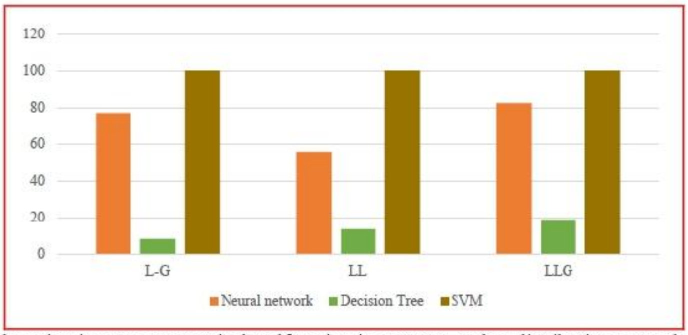

Fig. 12: DoS detection in an unsymmetrical malfunction in an IEEE-15 bus distribution network based on CPL

The accuracy of DT's cyberattack classification in the case of an unsymmetrical fault is 8.6% for L-G, 13.43% for L-L, and 18.8% for L-L-G faults, respectively. The accuracy of the NNN's assault prediction was 76.66%, 55.46%, and 82.4%. SVM identified the cyberattack under L-G, L-L, and L-L-G fault situations with 100% classification accuracy.

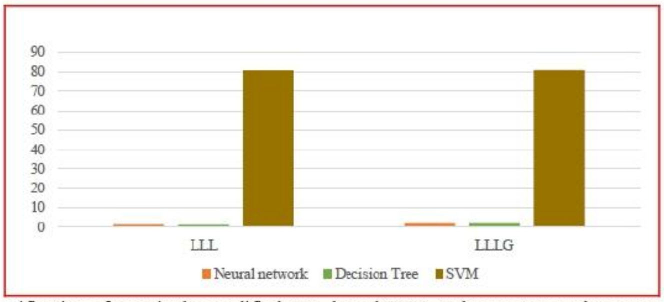

Fig. 13: Classification of DoS in the modified CPL-based IEEE-15 bus system under symmetrical faults

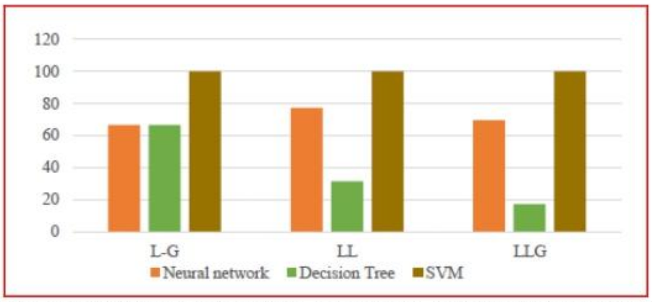

Fig. 14: Classification of DoS in the modified CPL-based IEEE-15 bus system under unsymmetrical faults

In a similar vein, DG-based modified IEEE-15 bus systems have been subject to a DoS attack. The accuracy of classification is displayed in Figures 13 and 14. With 66.32, 31.58, and 16.92% for unsymmetrical fault types, DT has the lowest classification. L-G, L-L, and L-L-G fault classification accuracy has increased at a rate of 66.36%, 77.29%, and 69.25%, respectively. When symmetrical faults occur, the cyberattack is classified as a system fault by DT and NNN. As seen in Figure 4, SVM can classify cyberattacks with a maximum accuracy of 80.28% and 81.08%. SVM achieves 100% accuracy in classifying the DoS in unsymmetrical fault data.

The categorization outcome of the DoS attack in the modified IEEE-15 bus system and the cyber-physical layered IEEE-15 bus system is shown in figure 15. The SVM classifier has the highest accuracy of 90.28% in classifying DoS attacks in the IEEE-15 bus system, while the DT classifier has the lowest accuracy of 29.05%. The SVM has a maximum validation of 90.12%.

With validation percentages of 73.89%, 86.19%, and 93.21%, respectively, the DT, NNN, and SVM are highly effective in the context of the modified IEEE-15 bus system. The SVM classifier identified the cyberattack with the best accuracy of 92.58%, while the DT had the lowest performance in attack classification with a rate of 23.54%

Sr. No.	Machine Learning Classifier	Features	Preset	CPL-based IEEE-15 bus system		CPL-based modified IEEE-15 bus system	
				Validation	Accuracy	Validation	Accuracy
01	Decision Tree	Voltage and Current	Fine Tree	78.86	29.05	73.89	23.54
02	Neural Network		NNN	88.95	66.88	86.19	43.05
03	SVM		Fine Gaussian SVM	90.12	90.28	93.21	92.58

Fig. 15: Analyzing DoS attacks in comparison with machine learning methods

7. Conclusion

In this study, a comprehensive analysis was conducted on the cyber vulnerabilities associated with Distributed Generation (DG)-based power networks, particularly focusing on Active Distribution Networks (ADNs). The integration of advanced communication technologies within these systems has opened new avenues for efficiency, but simultaneously introduced significant cyber threats. Key cyberattacks such as False Data Injection (FDI) and Denial of Service (DoS) were modelled and investigated using a Cyber-Physical Layered (CPL) approach on the IEEE-15 bus benchmark and modified systems.

To effectively distinguish between physical faults and cyberattacks, machine learning classifiers—Decision Tree (DT), Nearest Neighbor Network (NNN), and Support Vector Machine (SVM)—were employed. The results demonstrate that while all three classifiers were effective to varying degrees, SVM achieved the highest detection accuracy, making it the most reliable technique among the evaluated methods.

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A Novel Neural Network Approach for Harmonic Distortion Detection in Power Systems

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ABSTRACT: Harmonic distortion in power systems can lead to inefficiencies, equipment failures and operational risks. Generally, the high order harmonics are introduced in a system when the electricity is controlled by electronics. Traditional detection methods, such as Fourier and wavelet analysis, often face challenges with real-time detection due to high computational demands. The harmonic measurements are conducted on Power Quality Analysers, Harmonic Analysers and numeric meters. This paper proposes a novel neural network-based approach for harmonic distortion detection, utilizing the pattern recognition capabilities of Artificial Neural Networks (ANNs).The proposed method is simple, cost effective and feasible.

KEYWORDS: Artificial Neural Networks (ANN), Sigmoid function, Chaining, Total Harmonic Distortion (THD), Gradient Descent Method

I. INTRODUCTION

Harmonic distortion occurs when the normal sinusoidal waveform of electrical signals in a power system is altered by the presence of additional frequency components, called harmonics [1]. In an ideal power system, the current and voltage follow a clean sinusoidal wave at the fundamental frequency, typically 50 or 60 Hz. However, when nonlinear loads such as computers, LED lighting or variable frequency drives are connected to the system, these may introduce harmonics—frequencies that are integer multiples of the fundamental frequency (e.g., 150 Hz, 300 Hz) [2].These harmonic frequencies distort the original waveform, leading to power quality issues as stated below.

- Increased power losses in transmission lines
- Overheating of equipment like transformers and motors [3].
- Malfunctions or failures of sensitive electronic devices [4][5].
- Interference with communication systems.

Managing harmonic distortion is critical to ensuring the efficiency, reliability and safety of power systems [6][7].
Artificial Neural Networks (ANNs) are computational models inspired by the structure of human brain and function[8]. These are composed of interconnected layers of nodes, called neurons that work together to process information, learn patterns and make predictions. ANNs are a key technology in machine learning and are used to solve complex tasks like image recognition, speech processing and data classification[9].

The typical ANN consists of: the following main components.

1. Input Layer: Receives the raw data or input features.
2. Hidden Layers: These layers perform intermediate computations and extract features by adjusting weights and biases. The more hidden layers, the deeper the network.
3. Output Layer: Produces the final prediction or classification based on the learned data [10].

The ANNs learn through a process called training, which involves adjusting the weights of connections between neurons based on the error in predictions. This is done using optimization techniques like backpropagation and gradient descent. Over time, the network improves its ability to recognize patterns and make accurate predictions[11].These are highly flexible and capable of modeling nonlinear relationships, making them powerful tools for applications such as

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image and speech recognition, natural language processing and infields like power system analysis, including harmonics detection [12].

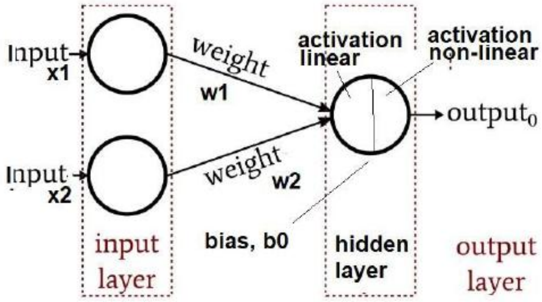

Fig.1. Two Input, One Output ANN

Fig 1 illustrates Two Input, one output ANN applied through input layer, hidden layer and output layer forming feed forward path.As discussed above the main components are as follows.

- Input Layer: Raw or pre-processed current/voltage waveform data (from sensors or power meters).
- Hidden Layers: One or more layers of neurons with activation functions like ReLU, Sigmoid, or Tanh, to capture non-linearities in the data.
- Output Layer: Predicted harmonic orders or THD levels [13].

II. DETECTION OF HARMONICS

Harmonics are integer multiple of fundamental quantity of current and voltage. Harmonics in a non-linear load are detected by analyzing the distortion in the current or voltage waveform. The non-linear loads such as computers, fluorescent lights and power electronics draw current in a non-sinusoidal manner, which distorts the waveform and creates harmonics. Conventionally, the harmonics are detected generally using following techniques.

1. Fourier Transform (FT)
The most common method to detect harmonics is through the Fourier Transformer more specifically theFast Fourier Transform (FFT). This method decomposes the waveform into its sinusoidal components, identifying the fundamental frequency and the harmonic frequencies.

Theresult of an FFT analysis show the magnitude and phase of the fundamental frequency (usually 50/60 Hz) and its harmonics (multiples of the fundamental frequency like 2nd, 3rd, etc.).

2. Total Harmonic Distortion (THD) Measurement
Total Harmonic Distortion is a metric used to quantify the harmonic content. It is calculated as the ratio of the root mean square (RMS) value of all harmonic components to the RMS value of the fundamental frequency.

A high THD indicates significant harmonic presence, which can be measured using harmonic analyzers or power quality analyzers or numeric meters.

3. Harmonic Analyzers
Specialized equipment such as harmonic analyzers or power quality meters can be used to measure and detect harmonic components in electrical systems. These devices are capable of real-time monitoring and analyzing waveform distortions caused by harmonics.

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4. Digital Signal Processing (DSP)
DSP techniques can be used to process the sampled signals from the power system. Algorithms such as Discrete Fourier Transform (DFT), wavelet transforms,or Kalman filtering are often employed for harmonic detection, especially in real-time applications.

5. Artificial Intelligence and Machine Learning Approaches
AI and ML-based methods, such as neural networks and fuzzy logic, can also be employed to detect harmonics. These methods are trained to recognize patterns of distortion that are indicative of harmonics and can be more adaptive to complex, dynamic environments.

6. Wavelet Transform
The Wavelet Transform provides time-frequency analysis, which is useful for detecting harmonics that vary over time. This is especially useful in systems where the load conditions change frequently.

1. Problem Formulation: Harmonics Detection
In non-linear loads, the waveform of the current or voltage is distorted, resulting in harmonics that are multiples of the fundamental frequency. Detecting these harmonics is essential in maintaining power quality, avoiding overheating and reducing losses.

Neural networks can be used to classify and estimate the presence of harmonic components in real-time, based on patterns in the distorted waveforms.

2. Neural Network Architecture for Harmonics Detection
Feed forward Neural Networks (FNNs)or Convolutional Neural Networks (CNNs)can be employed to identify harmonic patterns in time-series data. This is discussed in his paper.

Recurrent Neural Networks (RNNs), specificallyLong Short-Term Memory (LSTM) networks, can be used for time-dependent harmonic analysis, as harmonics in a power system often exhibittemporaldependencies[14].

4. Preprocessing for Neural Networks

5.Combining Neural Networks with Traditional Techniques
- Neural networks can be integrated with traditional FFTorWavelet Transform methods. The transform can serve as a feature extraction technique, providing the frequency components to the neural network [15].
- Alternatively, neural networks can be used for post-processing, where traditional methods like FFT estimate the harmonics, and the neural network fine-tunes orclassifies the harmonics based on learned patterns [16].

6. Evaluation Metrics
- The neural network model should be evaluated based on its accuracy in detecting the correct harmonic order and magnitude. Typical metrics include:
- Mean Absolute Error (MAE) and Root Mean Square Error (RMSE): To measure the accuracy of harmonic magnitude predictions.
- Classification Accuracy: If the network classifies harmonic severity or order.
- Real-time performance: To assess how quickly the network can process and output results in a live environment

7. Challenges and Considerations
- Training Data: High-quality training data with a wide range of harmonics and load conditions is critical for accurate detection.
- Generalization: Neural networks need to generalize well to different loads and harmonic conditions to be effective in diverse settings.
- Hardware Limitations: Real-time detection requires optimized neural network architectures that can run efficiently on hardware with limited processing power (e.g., embedded systems in power quality meters) [17].

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By utilizing neural networks, more adaptive, real-time system for harmonic detection can be developed that improves upon traditional methods. Neural networks can capture complex relationships and adapt to varying load conditions, making them a powerful tool in the on-going effort to maintain power quality in systems with non-linear loads.

III. THE ANNBASED HARMONIC DEIECTION MODEL

The human brain is made up of billions of neurones, which are nerve cells. Dendroids and axons are the connectors that connect the neurones. The eyes, nose, touch, etc., all provide input to the neurones. Neurones process the inputs they receive before forwarding them for additional activation. The term "Biological Neural Network" (BNN) refers to this network made up of neurones and dendroids. Working with parallel processing, the BNN [7].

The development of artificial neural networks is based on this concept. Inspired by the BNN, ANNs are massively parallel computing systems made up of several processors connected to one another[8].

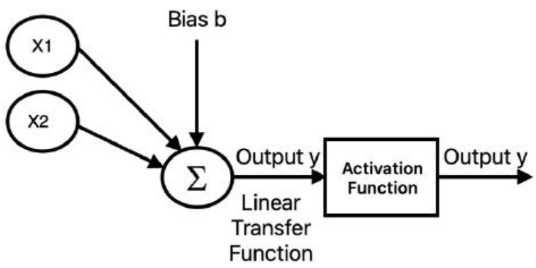

Fig.2. ANN Model for harmonic detection

An ANN model for harmonic detection is shown in Fig. 2. The input layer, hidden layer, and output layer are the three main layers that make up the ANN model. At the input layer, the ANN receives the input signals x1 and x2 as fundamental current or voltage and harmonic current or voltage, respectively.

Here the Current THD is calculated as root mean square of total harmonic current divided by fundamental current. Refer equation 1. On similar lines, the Voltage THD is calculated from total harmonic voltage and fundamental voltage.

$$I_{THD} = \frac{\sqrt{\sum_{h=2}^{\infty} I^2{}_h}}{I_1} \text{ .... (1)}$$

The ANN is formed between two inputs –fundamental I1 and harmonic component Ih. These parameters may be current (I1, Ih)or voltage (V1 and Vh). The output of ANN will be current or voltage harmonic distortion.

The bias signal b is given additional to input signals. Bias can be introduced at the input layer. It is possible to take input x0 with weight w0 in the input layer so that w0=b, which is bias. Synoptic weights $w0$, $w1$, and $w2$ construct linkages that feed these inputs to a linear transfer function at the hidden layer. At the output layer, each input is altered by a weight (for example, multiplied by weights), and the result is y[9]. In the case of BNN, this so-called perceptron functions similarly to a neurone in a junction. Equation 2 mentions a linear equation that represents the expression for output y.

$$y = w_0x_0 + w_1x_1 + w_2x_2 = \Sigma_0{}^2 w_ix_i \text{...... (2)}$$

An activation function is used to further process the output y in order to provide a scalable output. Numerous activation functions exist, including hyperbolic tangent, sigmoid, and rectified linear unit (ReLU). An activation function that produces output Y between 0 and 1 is the sigmoid function. Equation 2 provides the expression for the sigmoid function. [10].

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$$Y = \frac{1}{1+e^{-y}} \qquad (3)$$

The network forming a sequence of input layer, hidden layer and output layer is called feed forward network. The output so obtained through a feed forward network is called as predicted output. The predicted output (Y) is compared with the targeted output (T) in case of supervised learning algorithm. Error, represented by the letter e, is the difference between the intended and projected output [11]. The mistake should ideally be obliviously zero in order to produce the desired result. At its gradient with regard to weights, the error would be at its lowest. The gradient is the rate at which the error changes in relation to the weight (de/dw). It is necessary to return from mistake to weight in order to calculate gradient. We refer to this process as back propagation. Back propagation can be done in a variety of ways, including chaining, the gradient decent approach, and others. [12].

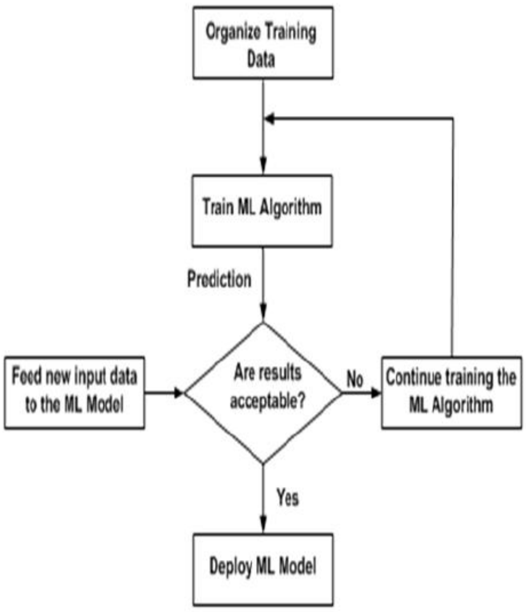

Fig.3. Flow chart for machine learning algorithm

Fig 3 shows a Flow chart used in this paper. The ML model is tested under training data and testing data. The model is deployed when the results are acceptable.

IV. OBSERVATIONS

Initially, status 0 indicates normal condition whereas status 1 indicates that the harmonic distortion has been detected. Based on previous results obtained from field, the datasets have been prepared comprising of three parameters fundamental current (I1) and harmonic current and status. The sample training data for current harmonics is furnished in Table I Status indicates targeted output. Both regular and warped situations can be seen in this historical data. Python initialises the weights w1, w2, and bias at random. Equation (1) is used to determine the output y. The output Y is calculated using the Sigmoid function, as illustrated in Fig. 2.It is specified that mode 1 is when the distortion event is noticed. Therefore, the system is normal if the output value is smaller than the neural network's threshold of 0.05; otherwise, the neural network generates the harmonic distortion event.

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TABLE 1.OBSERVATIONS - ITHD

Fundamental Current Amp, I1	Harmonic Current Amp ,Ih	Current THD %	Status
0.99	0.001	0.101	Not distorted
0.98	0.004	0.408	Not distorted
0.90	0.044	4.888	Not distorted
0.87	0.0045	0.517	Not distorted
0.8	0.046	5.75	Distorted wave
0.78	0.065	8.333	Distorted wave
0.75	0.045	6	Distorted wave
0.92	0.025	2.717	Not distorted
0.91	0.071	7.802	Distorted wave
0.94	0.045	4.787	Not distorted

The difference between the main meter and check meter units is used to calculate the theft units displayed in Table I. Zero is used to truncate a very small difference.

TABLE II. OBSERVATIONS(VTHD)

Fundamental Voltage Volts, V1	Harmonic Voltage Volts, Vh	Voltage THD %	Status
63.5	0.012	0.018898	Not distorted
62.12	0.045	0.07244	Not distorted
63.99	0.047	0.073449	Not distorted
63.12	0.0045	0.007129	Not distorted
62.12	0.052	0.082869	Not distorted
63.45	0.022	0.034673	Not distorted
63.66	0.065	0.102105	Not distorted
63.04	0.998	1.583122	Not distorted
63.12	0.065	0.102978	Not distorted

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63.05	0.448	0.710547	Not distorted

Targeted output T and output Y are compared. The difference between the intended output (T) and the expected output (Y) is then used to calculate error e. Equation 4 uses the chaining method to calculate the square of error and differentiate error e with regard to weights w1 and w2.

$$\frac{\partial e}{\partial w} = \frac{\partial e}{\partial Y}\frac{\partial Y}{\partial y}\frac{\partial y}{\partial w} \qquad (4)$$

A number of consecutive repetitions are used to carry out the chaining. When the weight values remain constant over iterative cycles, convergence is considered to have been achieved. When convergence occurs, the error is at its lowest. The predicted output thus gets closer to the desired output.

On similar lines three parameters namely fundamental voltage (V1) and harmonic Voltage (Vh) and status are measured and furnished in Table II.

```
def which_data(fundamental,distortion):
  y=point[0]*w1+point[1]*w2+b
  Y=sigmoid(y)
  print('Y=',Y)
  print('error=',Y-T)
  print('w1=',w1)
  print('w2=',w2)
  if Y<0.05:
   os.system('status normal')
   print('status normal')
  else:
   os.system('Harmonic distortion detected')
   print('Harmonic distortion detected')
```

```
which_data(0.09, 6.111)
```

```
Harmonic distortion detected
```

Fig.4. Sample PythonPsudo code for harmonic detection

The code is written in Python language. Fig.34 illustrates Sample Python Psudo code for harmonic detection
Future research could explore the application of more advanced neural network architectures, such as convolutional or recurrent neural networks, to further enhance detection capabilities. Additionally, integrating this model with real-time monitoring tools could provide a comprehensive solution for proactive management of power system harmonics. Ultimately, the integration of AI-driven methods such as this can significantly contribute to the stability and reliability of the modern power grids, ensuring optimal performance and compliance with international power quality standards.

V. CONCLUSION

In conclusion, this paper presents a novel approach for detecting harmonic distortion in power systems using neural networks. The proposed method demonstrates the potential of machine learning to address challenges in power quality monitoring, offering higher accuracy and adaptability compared to traditional techniques. By leveraging neural networks, the system can effectively identify complex harmonic patterns, enhancing both real-time detection and mitigation of distortions in power distribution networks. This approach opens new avenues for automating power system diagnostics, minimizing manual intervention, and ensuring continuous power quality. The proposed method is novice, feasible and cost effective.

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Artificial Intelligence Methods for Hybrid Energy System Optimization

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Abstract

Here are some new topics emerging in the different disciplines of renewable energy to understand how experts and central links work. In the new era of artificial intelligence and data analytics, suggestions of new services and products can be used quickly and effectively in the new era of digital marketing. Awareness of the need to mitigate climate change and rising energy costs has prompted many countries to implement a new energy strategy to promote renewable energy. Solar energy, wind energy and hydro energy are renewable energy sources that do not harm the environment and can be used widely. All load needs can be met with more energy and reliability than the use of environmentally friendly electricity, and the process continues to combine this information to create a combination of ideas. Optimization and optimization of renewable energy systems has been extensively studied and this AI study for renewable energy systems provides a comprehensive review of the literature on AI optimization schemes to gain access to renewable energy to improve employment.

Keywords: ***Artificial Intelligence, Hybrid Energy System, Optimization***

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1. Introduction

Due to the uncertainties and disadvantages of renewable energy production, renewable energy systems are becoming increasingly common. Model-based systems will struggle to meet the analysis, operation and management challenges of renewable energy in the future. With the development of smart grids in recent years, energy users are collecting more and more information from smart meters and advanced measuring devices [1]. It supports the ease of use of artificial intelligence (AI) and hybrid access (HRES) that can learn important information directly from big data to solve complex problems without thinking.

Artificial Intelligence (AI) technologies play a crucial part in the design, analysis, forecasting of operational improvements and management. Algorithms for modelling and controlling or predicting electrical work are complex and involve many equations, energy and time requirements.

AI systems can learn important data patterns from large amounts of data instead of complex rules and math. Long-term meteorological data, such as solar radiation, temperature, or wind data, are necessary for the planning, administration, and operation of solar energy. For most areas of interest, such long-term assessment is usually not available, or if it does, there are many disadvantages (such as bad data, the system not being long enough, and other things). The smart machine seems to be one of the strongest candidates for solving these problems. In this level, artificial intelligence is introduced in relation to solar energy, with a focus on neural networks, fuzzy logic, and genetic algorithms. Specifically, it discusses how AI methods can be used for applications such as solar radiation prediction and modelling, solar energy capture, efficiency and management, photovoltaic (PV) systems.

2. **Artificial Intelligence Techniques**

Artificial intelligence seeks to comprehend the human mind in order to produce clever solutions to some challenging problems [2][3], but understanding that the human brain is a difficult problem to solve, although it is difficult to understand. Advances in artificial intelligence have increased the burden on humans, and while only a few areas have outstripped the work of the brain, other industries have surpassed the brain by creating technologies such as computers that can handle thousands of tasks. For the average human mind, it is impossible to count a second. Artificial intelligence is used in many fields such as information databases, accounting, data retrieval, product design, production planning and work distribution, as well as in business, medicine and food, management, biometrics and forensics. Artificial intelligence, mathematical learning, neural learning, evolutionary learning, etc. Based on various learning theories such as Among them, neural learning is often used for a variety of applications. ANNs are the most important machine in neural learning. When the weight of an input exceeds a threshold, the neuron fires producing an output in response to some action. ANNs can improve learning capabilities by adjusting their results to correct errors in the output. Artificial intelligence seeks to comprehend the human mind in order to produce clever solutions to some challenging challenges. In addition, methods based on neural, statistical and evolutionary learning are also used for many applications. Mathematical studies in artificial intelligence, Bayesian and Naive Bayesian models, clustering, hidden Markov models, nearest neighbor models, etc. Artificial intelligence technology in the smart grid can be divided into the following categories.

- ES: A person who specializes in methods used to solve problems.
- Supervised Learning: An example of artificial intelligence that studies objects and patterns of objects to predict the prices of new products.
- Unsupervised Learning: An unsupervised type of machine learning is used to identify similarities and differences in data.
- Further Learning (RL): The difference between supervised and unsupervised learning as its legal guardian seeks to achieve the highest reward goal.
- Ensemble approach: Combine the benefits of multiple algorithms to get around a single algorithm's drawbacks and gain overall performance.

3. **AI In Renewable Energy**

Artificial Intelligence (AI) technologies play a crucial part in the design, analysis, forecasting of operational improvements and management. Revolutionary technologies and digital industries with artificial intelligence. It has become an essential part of everyone's daily interaction with the digital world: search engines are an essential part of the internet; recommendations are coordinated with content provided by social media, streaming services and online businesses; Available on all platforms. virtual assistance. This innovation is gradually happening in many other industries, but there are many applications of intelligence that are not used in other areas. That's why it's important to help AI innovation and tailor it to their specific needs. Today, new and improved tools already use AI elements to improve processes and build capabilities that were not possible in the past. If this trend continues as it is now, AI-enriched tools will likely be as important a part of engineering in the future as computer-aided design (CAD) software today. The AI can be used to optimize applications in clean energy systems such as solar panels, wind turbines and water systems by identifying the most efficient products from this machine and then determining the most efficient repeatable process. AI is used in the design, optimization, forecasting, management, distribution and policy of all types of renewable energy (wind, solar, underground, hydro, marine, bio, hydrogen and hybrid). Figure 1 shows simple examples of different types of renewable energy and artificial intelligence. Details of AI applications in renewable energy are as follows.

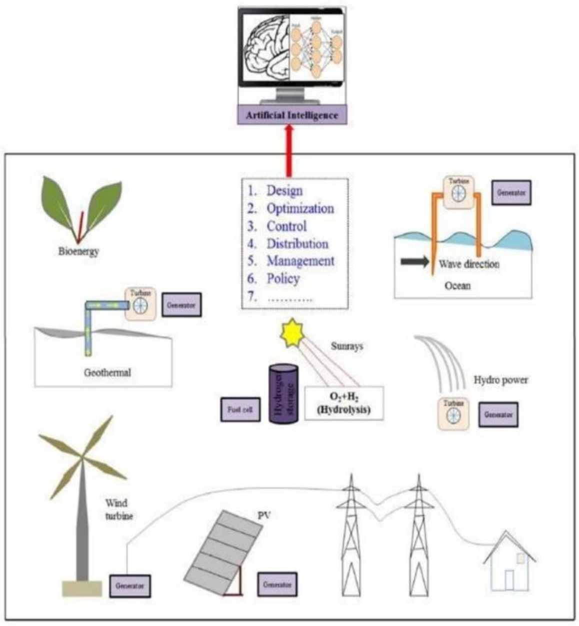

Fig. 1 . A schematic representation of application of AI in different sources of RE

A. AI in Wind energy

In order to timely fix the malfunction of the wind turbine, it is necessary to quickly and reliably check for changes that will indicate damage and more. This information is instantly available from SCADA or Condition Monitoring System (CMS) data, providing effective monitoring with quick responses and plans before larger problems arise. "WIND Center" is equipment independent of the facility; It monitors the health of wind turbines or individual plants in real time through predictive analysis and powerful software without the need for additional sensors.

All important and monitoring results of the wind farm can be viewed on the dashboard at any time. ZSW has focused on the development of wind turbines for many years through research and machine learning (ML). Consider the many interactions between weather models, satellite data, weather forecasts, historical wind data, and future weather for each location. As part of the WINSENT briefing, ZSW continues its expertise in wind research. We use new machine learning techniques to improve product predictions and optimize models for future energy storage solutions (such as electrical appliances, batteries for energy storage). The ZSW also used the clever design of the bird recorder, the name of the device that can capture birds near wind turbines and identify different species. If a group of birds fly into the rotor blades, the control center intervenes immediately and takes the necessary action, such as reducing speed, to avoid a collision. This is one way to ensure that technology supports nature conservation.

B. AI in Solar energy

AI will change the solar industry in many ways. AI is used to improve and tune solar panels to produce better and more efficient solar panels. For example, to determine the best position of solar panels, researchers at Stanford University developed a machine learning algorithm. In order to deliver reliable and efficient projects, it is important to use artificial intelligence to predict the potential of renewable energy. As sensors become more common, solar and electricity could provide data back to help AI predict potential levels.

Solar start-ups can use measurement tools to increase efficiency and find new revenue streams from smart energy systems. Some solar companies even have apps that let homeowners know when their battery pack is ready to charge or discharge, so homeowners can take steps to ensure they don't lose power at that moment. AI could also allow consumers to monitor their energy use from anywhere with a Wi-Fi connection.

C. AI in geothermal energy

Reservoirs are important assets to the underground economy. Deterioration of reservoir performance will affect the sustainability of future production. Production forecasting is important when used with some negative assumptions when planning future production strategies. Reservoirs are porous environments with a high degree of heterogeneity and ambiguity, so the need to use production estimates is erroneous. This study goals to elaborate a method for improving and reckoning energy consumption by removing the assumptions. Artificial Intelligence (AI) is another method that can be used to optimize and forecast production in warehouses with high uncertainty. The AI model was developed using parametric data from the study area in Indonesia's Batuha Tropical Region. AI models that predict production from geothermal water are more accurate in calculating production estimates because they use real data and remove guesswork.

D. Artificial Intelligence in Hydropower

One of the most promising forms of renewable energy is electric power. However, constructing a large building requires a large initial investment. Efficiency research, detailed planning, construction planning and timely operation are important tasks for power plants. Power generation is primarily dependent on flow and head. Therefore, accurate flow and head estimates are important for cutting decisions. Erosion, cavitation and O&M are major problems in power generation. Artificial intelligence (AI) is gaining popularity and can be used for site selection, measurement, and O&M optimization. This article presents a literature review on the use of artificial intelligence in hydropower and attempts to identify potential areas for the future of hydropower. However, constructing a large building requires a large initial investment. Efficiency research, detailed planning, construction planning and timely operation are important tasks for power plants. Power generation is primarily dependent on flow and head. Therefore, accurate flow and head estimates are important for cutting decisions. Erosion, cavitation and O&M are major problems in power generation. Artificial intelligence (AI) is gaining popularity and can be used for site selection, measurement, and O&M optimization. This article presents a literature review on the use of artificial intelligence in hydropower and attempts to identify potential areas for the future of hydropower.

E. AI in ocean energy

Ocean energy can use many sources and different types of energy such as thermal, kinetic, electric and gravitational to solve fire, electricity and other problems in the world. Based on the principles of thermodynamics, fluid mechanics, aerodynamics and mechanics, a series of stepped hydroelectric generators were built on the vertical axis and advanced electrical conversion equipment was used to capture the power of the ocean and the known electricity production. .However, the power characteristics of various marine generators vary with time and place. For example, the density of ocean water today is 1000 kg/m3, whereas in the past the density of ocean water was about 1. 2 kg/m3, turbines are now more powerful than wind turbines of equal capacity. Integrating ocean energy into electricity can facilitate the transition to a carbon neutral environment with clean electricity at a time when transitions are weak and invisible across grid power. Demand management is based on the concept of energy distribution, where hybrid energy storage with different response times can adjust the demand curve like lightning to improve mixing performance.

F. AI in Bioenergy

Bioenergy is widely recognized as a sustainable alternative to fossil fuels. However, large-scale use of biomass-based energy is limited by changes in food availability, economic changes and supply problems. In recent years, artificial intelligence (AI) is a new concept applied to bioenergy systems to solve these problems. The purpose of this review is to identify the unique potential of various artificial intelligence technologies in solving bioenergy research problems and improving the performance of bioenergy systems. We focus on AI research on different topics, products, AI methods, big data and operations. We examine the applications of artificial intelligence throughout the life cycle of bioenergy systems. We identified four areas with the most AI applications, including (1) biomass production forecasting, (2) biomass conversion process efficiency forecasting and various conversion and technology urine, and (3) biofuel energy and bioenergy final efficiency. Use the system; (4) Supply chain and optimization. According to the review, AI is particularly important in generating data that are difficult to measure directly, creating biomass conversion and biofuel end-use models, and overcoming modern computational methods for the design and optimization of bioenergy supply chains.

G. AI in hydrogen energy

Accurate estimation of energy production and use is important for the realization of renewable energy potential. Machine learning and Artificial intelligence are key concepts in most applications.

Hydrogen chains are no exception. Machine learning and Artificial intelligence are used to investigate earlier results , improve the current performance and forecast the upcoming events. Artificial intelligence uses sustainable energy (solar, wind, etc.).

4. Optimization objectives in HRES

A. Designing objectives with ESS

It The initial cost of installing a solar or wind generator is designed to be higher than a diesel generator of the same size, but the operating and maintenance costs are always lower than for electric machines. It can bridge the gap between maximum demand and power generation between Therefore, creating a competitive HRES is a huge challenge for the designer, with many constraints that must be met. Reliability and cost must be balanced in the design strategy.
For many continuous systems in HRES, many weaknesses such as orientation, uncertainty, and health affect decision-making strategy [5].

B. Sizing objectives

Choosing the best generator is important for efficient and effective use of renewable energy. Optimized method to ensure lowest cost when measuring and using all HRES products. This ensures that the system can operate in a clean environment with good investment and reliability. Many researchers have written reviews on HRES design optimization techniques. The most common targets for increasing HRES size are economic and environmental targets.

C. HRES control and energy management

The best energy management strategies ensure efficient and reliable integration of energy. Generally, a control system must determine and distribute the actual voltage and current from each power source while keeping the output voltage and frequency within desired limits. Most authors use state of charge, bus voltage and bus frequency as control parameters for power management in HRES. To establish an adequate energy management system at HRES, renewable energy sources and loads are estimated in the first stage and optimized in the second stage. The control system is divided into three groups, central, distributed and hybrid control paradigms, in all paradigms, each energy source is assumed to have its own local controller, which decides the best operation of the led unit.

5. Application of ANN in Renewable Energy

ANN ANNs are used by many researchers for modeling and forecasting in the field of renewable energy systems. This article describes each of these applications in context. Due to field limitations, the authors' recent work in this area provides additional details.

A. Modeling of Solar Steam Generators

ANNs have been used to model various types of solar steam generators. The system uses a parabolic corrugated material, a flash cup, a high pressure pump and a connecting pipe.
Some of the work done for this system is described here. The stop is defined as the ratio of the energy absorbed by the receiver to the energy apparent at the concentrator aperture. Optical properties can be determined from the light source. This is important in determining the overall efficiency of the solar concentrator collector. The neural network is able to calculate factors related to differences less than 0. A 4% reduction compared to various estimates in energy deposition (EDEP) computer code [7][8].

B. Solar Water Heating (SWH) Systems

30 ANN-trained people are familiar with the SWH system with an average collection point of 1. 81m 4.38m wb. Both open and closed are considered for both horizontal and vertical storage tanks. Also, try to include different weather conditions so that the network can learn to accept and deal with different conditions. The information provided as input includes the collection area, the tank heat loss coefficient and volume, the tank type, the system type and ten basic parameters for measuring solar radiation each day, the average temperature of the start date and the water temperature in the tank. electrical sockets used by Enerji are pulled from the system and keep hot water. Unknown information is used to check the accuracy of the prediction.
Estimated values obtained were 7.1% and 9.7%, respectively [9]. These results suggest that the method can be effectively used to estimate the useful energy extracted from the body and the temperature of stored water. The advantages of this approach over algorithmic methods are speed, simplicity, and the ability of the network to learn from examples. In addition, real weather data is used for network training, which yields better

results compared to other models based on weather year (TMY) data without real-world work.

C. Wind speed prediction

Trained AI predicts the monthly average wind speed in the Cyprus region, no data. Data from three sites from 1986-1996 were used to train the network, while data from 1997 were used for validation [10]. Both learning and estimation are done with acceptable accuracy. Two multilayer ANN architectures of the same type, one with 5 neurons (moon, 2m and 7m wind speed, two stations) and the other with 11 neurons in the input layer, were tested. 11 The input data added to the network are the x and y functions of weather station. When presented with unknown data (1997), the maximum percentage difference from the two networks is 1.

8% and 5%, which is very interesting. These two networks can be used for different types of business, for example, the five-entry input can be used to fill in missing data in the data, while the 11-input network can be used to estimate the average wind speed at a nearby location. At first, signs can be inside (interpolated) or outside (extrapolated) our sign space.

6. CONCLUSION

As can be seen from the above description, experts and neural dynamics tools are widely used in the design and estimation of continuous power systems. All it takes to build these models is to select experts or neural network models that represent historical data and real processes. Of course, the number of applications presented here is not all or all, but examples of applications that demonstrate the value of AI methods. Like all other forecasting techniques, AI models have their relative strengths and weaknesses. There is no rule about when an application should have this particular process.

7. REFERENCES

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DEPARTMENT ACTIVITIES

1) Institute of Engineers [IE(I)]

Event organized in 2025-26

Activity Report

The All India Shri Shivaji Memorial Society's department of Electrical Engineering had organized following events under IE(I) in year 2025-26 **SEM I**

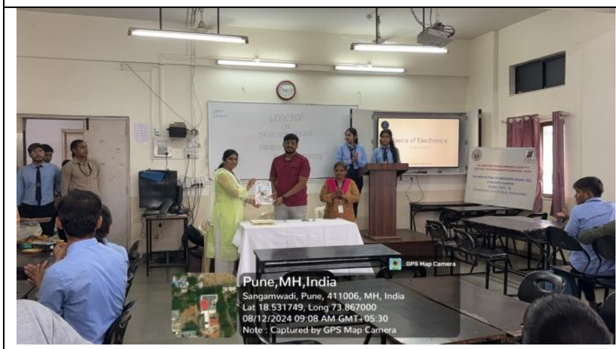
Sr. No.	Description of event	Date	Resource person (Organization)	Participation details (Class with numbers)	Department coordinator	Level of activity (Institute / National/ International)	PO	PSO
1	Coffee and conversation with alumnus	09/09/2025	Ms. Chaitrali Kakade, HCL Technologies Pvt. Ltd ,Pune	SY,TY, Btech 5	Faculty Organizer Dr. K. S. Gadgil, Student Organizer Ms. Vishakha Sahakar	Institute	5,6,7 ,12	1
2	Two days hands on training workshop on Industrial Approach of Electrical and Electronic circuits.	12/08/2025 and 13/08/2025.	Mr. Harsh Bhutada , Founder , Spark Innovation, Pune.	SY 42	Faculty Organizer Dr. K. S. Gadgil Student Organizer Krutika Dande	Institute	5,6,7 ,8,9, 12	1
3	Expert Lecture on Patent Filing	22/7/2025	Dr.Y.P Patil , Associate Professor , AISSMS IOIT , PUNE	TY Btech :64	Dr. V. P Kuralkar	Institute	5,6,7 ,8,9, 12	1

4	Expert Session on "ANSYS SOFTWAR E"	11/9/2025	Mr. Viki Kohad , Application Engineer , Ansys LF – Software, Pune and Mr. OmKar Veer, BDE, Khodiyar esolutions Pvt. Ltd, Pune	TY Btech 51	Dr. V. P Kuralkar	Institute	5,6,7 ,8,9, 12	1

Glimpses:

IEI Activities 2025_26 Sem I

Coffee and conversation with alumnus Ms. Chaitrali Kakade, HCL Technologies Pvt. Ltd ,Pune on 09/09/2025



Two days hands on training workshop for SY by Mr. Harsh Bhutada , Founder , Spark Innovation, Pune on 12/08/2025 and 13/08/2025.

Expert Lecture on Patent Filing by Dr.Y.P Patil , Associate Professor , AISSMS IOIT , Pune on 22/7/2025

Expert Session on "ANSYS SOFTWARE" by Mr. Viki Kohad , Application Engineer , Ansys LF – Software, Pune and Mr. OmKar Veer, BDE, Khodiyar esolutions Pvt. Ltd, Pune

on 11/09/2025

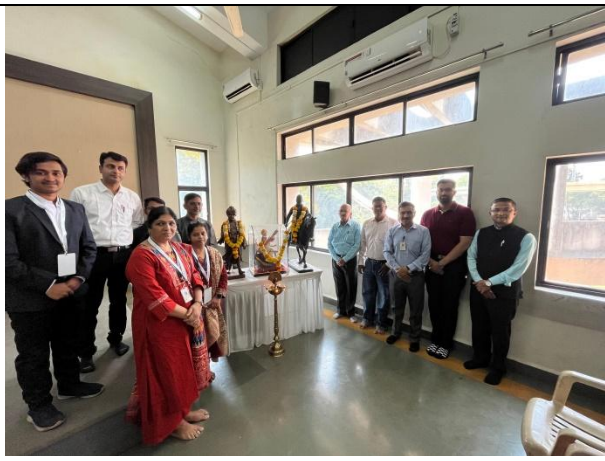
The All India Shri Shivaji Memorial Society's department of Electrical Engineering had organized following events under IE(I) in year 2025-26 **sem II**

Sr. No.	**Description of event**	**Date**	**Resource person (Organization)**	**Participation details (Class with numbers)**	**Department coordinator**	**Level of activity (Institute/ National/ International)**	**PO**	**PSO**
1	"Coffee and Conversation" session with alumnus Mr. Pranav Vedpathak	9/3/2026	Mr. Pranav Vedpathak, Batch Service Specialist, Ginlong Technology, Mumbai	Btech 20	Dr.K.S.Gadgil	Institute	5,6,7,12	1
2	VYOMA 2026	27/3/2026	Mr.Arvind Kanade Mr.Shyam Kanetkar Mr. Amay Pataskar Mr. Sachin Mahajan Mr.Tajas Kulakarni	65 Teams from all India	Dr.A.D.Shiralkar Dr.K.S.Gadgil	National	5,6,7,8,9,12	1

Glimpses:

IEI Activities 2025_26 Sem II

"Coffee and Conversation" session with alumnus Mr. Pranav Vedpathak, 2017 Batch , Service Specialist, Ginlong Technology, Mumbai on 9/3/2026

	
National level prototype making Competition VYOMA 2026 conducted on 27/3/2026	

Faculty Advisor

Dr A.D.Shiralkar

2) Indian Society for Technical Education (ISTE)

Event organized in 2025-26

Activity Report

The All India Shri Shivaji Memorial Society's department of Electrical Engineering had organized following events under ISTE in year 2025-26 **sem I**

Sr. No.	Description of event	Date	Resource person (Organization)	Participation details (Class with numbers)	Department coordinator	Level of activity (Institute / National/ International)	PO	PSO
1	Expert Session on Renewable Energy Development	20/08/2025	by Mr. Keadr Pathak , proprietor , Modern Technical Center , Pune	SY,TY, Btech 70	Faculty Organizer Dr. K. S. Gadgil, Mr. A, A. Joshi Student Organizer Ms. Vishakha Sahakar	Institute	5,6,7,12	1
2	Energy Conservation Awareness Drive.	27/08/2025 - 06/09/2025	Various Ganpati pandals in Pune City	SY,TY, Btech 40	Faculty Organizer Dr. K. S. Gadgil Student Organizer ,Ms. Krutika Dhande Ms. Vishakha Sahakar	Institute	5,6,7,8, 9,12	1
4	Expert Lecture on Copyright Filing Process.	06/08/2025	Dr. Sonali Rangdale , HOD, Assistant Professor AIDS GH raisoni international skill tech university Yerwada, pune	TY Btech :63	Dr.V. P Kuralkar	Institute	5,6,7,8, 9,12	1

Glimpses:

ISTE Activities 2025_26 Sem I

Expert Lecture on Copyright Filing Process conducted on 06/08/2025 for TY Btech Electrical students for the course IPR, delivered by Dr. Sonali Rangdale Madam Asst. Professor at JSPM's RSCOE, Tathawade

The All India Shri Shivaji Memorial Society's department of Department of Applied Sciences Engineering had organized following events under ISTE in year 2025-26 **Sem II**

Sr No	Description of event	Date	Resource person (Organization)	Participation details (Class with numbers)	Department coordinator	Level of activity (Institute/ National/ International)	PO	PSO
1	Mini Project Competition" for the students of Third Year B. Tech	15/4/2026	Mr. Sandip M. Chaudhari Dr. Vikas Kulkarni	TY Btech 70	Mr.Sandeep Raste	Institute	PO1 to PO12	1,2
2	One day Hands on workshop Residential Wiring Design using AUTOCAD	30/3/2026	Mr.Mayank Mehendale	TY Btech 70	Ms. Saba Shaikh	Institute	PO1 to PO12	1,2

Glimpses:

Mini Project Competition Evaluation by Judges on 15/4/2026

The resource person Mr Mayank Mehendale being felicitated by Dr. A D Shiralkar.

Mr Mayank Mehendale conducting the handson Workshop on "Residential Wiring Design using AUTOCAD" conducted on 30/3/2026

Dr.A.D.Shiralkar

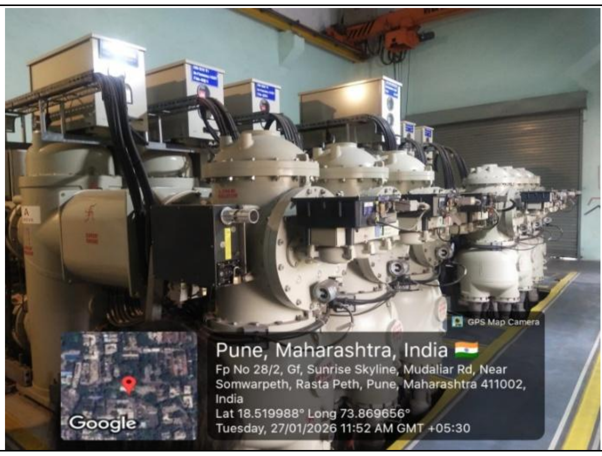
ISTE Faculty Advisor

3) IEEE, Student Branch

Events organized in 2025-26
Activity Report

Sr. No.	Department	Activity detail/ Topic	Date & Time	Resource Person	Partici-pants	Staff Coordinator	Level of activity	PO	PSO
1	Electrical	Industrial Visit 132kV GIS substation, Rasta Peth , Pune	27/01/2026	Mrs.Rashmi Raipurkar	TY	51	Institute	PO5 TO PO12	1,2
2	Electrical	Debate Competetion	02/02/2026	Mrs.S.S.Landge T and P Coordinator AISSMS IOIT	TY	16	Institute	PO5 TO PO12	1

Glimpses:



Industrial visit was arranged for the students of TY BTech Electrical to 132 kV GIS substation Rastapeth Pune on 27/01/ 2026

Debate competition was conducted for students of T Y B Tech class of Electrical Department under T&P cell.

Dr. A. D.Shiralkar
IEEE Student Branch Counselor

4) Renewable Energy Club

The department of electrical engineering established the Renewable energy club in 2007 under the guidance of the then HOD Mrs. M. H. Dhend . The club was initially funded by MEDA (Maharashtra Energy Development Agency) and MNRE (Ministry of New and Renewable energy sources).The club was established to enhance the knowledge of students about renewable energy sources and carry out various activities like energy conservation drives , poster competitions , quizzes, slogan competitions etc .

The students of the department carry out energy conservation drives and also celebrates Akshay Urja diwas on 20th August every year . The club also celebrates Energy conservation day every year on 14th December .

Akshay Urja Diwas Celebration

Students interacting with locals and informing them about energy conservation and use of Renewable sources at Ganpati mandals this year during Ganpati festival.

Faculty Coordinator

1) **Dr. K. S. Gadgil**
2) **Mr. A. A. Joshi**

5) Electrical Engineering Student Association (EESA)

EESA Report 2025-26

Sr No	Date	Activity/Event Name	Type and Mode	Student Coordinator
1.	29/08/2025	Human Knot	Sports	1.Vishakha Sahakar 2.Sanskruti Yewale
2.	29/08/2025	Arena Cricket	Sports	1.Pushkar Jawale 2.Mohit Tanpure
3.	29/08/2025	Electro Musical Chair	Sports	1.Annanya Kalokhe 2.Anjali Khot
4.	30/08/2025	Bgmi	E- Sports(Online)	1.Aditya Ingale 2.Dhiraj Patil
5.	31/08/2025	National Level Quiz	Technical	1.Jayesh Patil 2.Nilay Bhandari
6.	31/08/2025	Poster Competition	Technical	1.Riddhi Patil 2.Pranav Thathod
7.	29/08/2025	Art gala	Cultural	1.Shreyas Bachate 2.Aditi Thite
8.	29/08/2025	Photography	Cultural	1.TanushreeSukhadeve 2.Riddhi Patil
9.	09/09/2025	Teacher's Day	Cultural	1.Nilay Bhandari 2.Sameer Pande
10.	20/02/2026	Skit Performance: Alacrity 2026	Cultural	1. Nilay Bhandari 2.Sameer Pande
11.	23/03/2026	Table Tennis Competition	Sports (Outdoor)	1.Siddharth varde
12.	23/03/2026	Relay Race Competition	Sports (Outdoor)	1.Anushka Jadhav
13.	23/03/2026	Volleyball Match Competition	Sports (Outdoor)	1.Dhiraj Patil

14.	23/03/2026	Kabaddi Match Competition	Sports (Outdoor)	1.Kartik thorve
15.	17/04/2026	EESA Prize Distribution & Culmination Ceremony	Technical	1.Dhanad Khatu 2.Riddhi Patil

ENTHUSIA 2025-26

Enthusia 2025, organized by the Department of Electrical Engineering, was successfully conducted on **29th August 2025** with the central theme **"Industry 5.0."** The event aimed to highlight the evolving synergy between humans and intelligent technologies, reflecting the future direction of modern industry.

The event was **graciously inaugurated by our esteemed Principal, Dr. P. B. Mane**, whose presence inspired both participants and organizers.

Enthusia 2025 featured a vibrant and diverse lineup of activities, including:

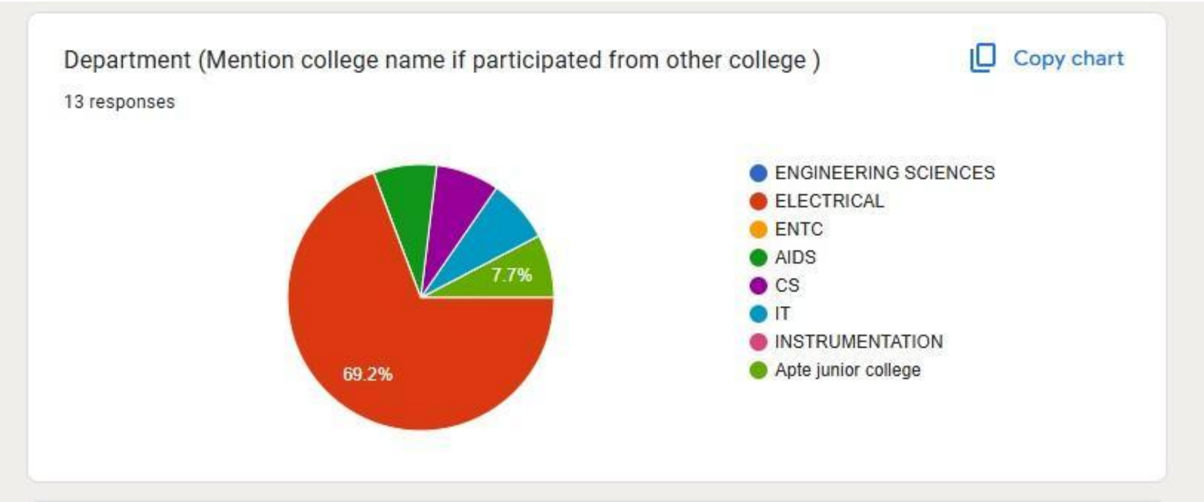
- **Technical events** that encouraged innovation, critical thinking, and problem-solving among students.
- **Cultural performances** that showcased creativity, talent, and the cultural spirit of the department.
- **Indoor sports competitions**, where enthusiastic participation from **both students and faculty members** created an engaging and energetic atmosphere.

The involvement of faculty in the sports events added a unique sense of camaraderie and strengthened the student–faculty bond.

The event witnessed excellent participation and coordination, promoting a balanced environment of **technology, creativity, teamwork, and holistic development**.

Enthusia 2025 concluded successfully, marking another memorable milestone in the department's tradition of hosting impactful and inclusive events

Title Enthusia Technical Event : National level Quiz on Industry 5.0	
Date: 31-08-2025	**Duration:10 am to 6 pm**
Organized by EESA Technical Committee	
Venue: Virtual	



Summary Report: National-Level Quiz on Industry 5.0

Enthusia 2025 Technical Event

The National-Level Quiz on Industry 5.0 was successfully conducted on 31st August 2025 as part of the technical events under *Enthusia 2025*. The event was organized by the EESA Technical Committee and held in a virtual mode, enabling participation from students across all departments.

A total of 13 students participated in the quiz, showcasing their knowledge, analytical skills, and understanding of the emerging concepts of Industry 5.0. The competition was conducted from 10:00 AM to 6:00 PM, maintaining a smooth and engaging flow throughout the day.

After a competitive series of rounds, Yash Chimbalkar secured the first position, emerging as the winner of the National-Level Quiz. His outstanding performance reflected deep conceptual clarity and quick thinking.

All participants will be awarded E-Certificates for their active involvement, recognizing their enthusiasm and contribution to the event.

The event concluded successfully, promoting technical awareness and encouraging students to explore advanced industrial technologies and future-ready concepts.

Title Enthusia Technical Event : Poster Competition	
Date: 30-08-2025	**Duration:10 am to 6 pm**
Organized by EESA Technical Committee	
Venue: Virtual	

Enthusia 2025 – Technical Event

The Poster Competition, conducted under *Enthusia 2025*, was held on 30th August 2025 in a virtual mode and organized by the EESA Technical Committee. The event aimed to enhance students' creativity, technical knowledge, and visual communication skills.

The competition was conducted from 10:00 AM to 6:00 PM, where participants presented their posters on a variety of engineering and technology-based themes.

A total of 5 students participated, each demonstrating creativity, research depth, and clarity during their presentations. After careful evaluation on the basis of presentation quality and technical information, Prachi Shinde was declared the winner of the Poster Competition.

All participants will receive E-Certificates for their active involvement and valuable contributions.

The event concluded successfully, inspiring students to showcase technical concepts through innovative and visually engaging poster.

Award Winners Details			
Sr. No.	**Student Names**	**Competition**	**Award**
1	**1. Vedant Gaikwad 2. Himanshu Chaudhari 3. Ratnesh Bhirud 4. Hitesh Jawale**	**Electrical Safety Video Making Competition**	**Winner Certificate + Rs.750/- Cash**
2	**1. Prerana Bais 2. Arya Chaure 3. Anushka Jadhav 4. Srishti Bane**	**Electrical Safety Video Making Competition**	**Runner-Up Certificate + Rs.500/- Cash**
3	**1. Shivam Adke 2. Kiran Gunjal 3. Pushkar Jawale 4. Shalvi Mohite**	**TY Mini Project Competition**	**Winner Certificate**
4	**1. Pranav Barne 2. Mahesh Dikhale 3. Gokul Arote 4. Shrutika Attarkar**	**TY Mini Project Competition**	**Runner-Up Certificate**
5	**1. Sushant Bhojane 2. Vishnu Pujari 3. Mukul Falak 4. Jaya Kotharkar**	**Technokratia: A Final Year Project Competition 2025-26**	**Winner Certificate + Rs.1000/- Cash**
6	**1. Samruddhi Ajaikar 2. Atharva Bedare 3. Shubham Chavanke**	**Technokratia: A Final Year Project Competition 2025-26**	**1st Runner-Up Certificate + Rs.700/- Cash**

Award Winners Details			
7	1. Aarya Tilekar 2. Amisha Pagote 3. Rohan Patil	Technokratia: A Final Year Project Competition 2025-26	2nd Runner-Up Certificate + Rs.500/- Cash
8	1. Omkar Koli 2. Tanushree Sukhadeve 3. Ashray Kamble	Technokratia: A Final Year Project Competition 2025-26	Consolation Certificate
9	Jayesh Patil	Best Tech Implementation Award	Momento
10	Janhavi Patange	Best Outgoing Student Award	Momento
11	Shubham Chavanke	Global Competitive Award	Momento
12	Vishnu Pujari	PQ Techno Entrepreneur Award	Momento
13	Mukul Falak	Versatile Achiever Award	Momento

Glimpses of the Event:

6) PQ Cell

Consultancy Provided to:GIS Integrated Supply India Private Limited, NSK Engineering Corporation, SAS Powertech Pvt Ltd, Aim Nonwovens and Interiors Pvt. Ltd, pqExcel Solutions LLP,Harmonizer India Pvt Ltd., Electrum, FHHL Private Limited, Kalyani Powertrain Limited, STRONICS, Kumar Picasso N & O Co-operative Housing Society Limited, Royal Embroidery Threads Pvt. Ltd., Brawn Energy, Pai Brothers Engineers Pvt Ltd, LOGICON TECHNOSOLUTIONS PVT. LTD, Alumatic Cans Pvt. Ltd.

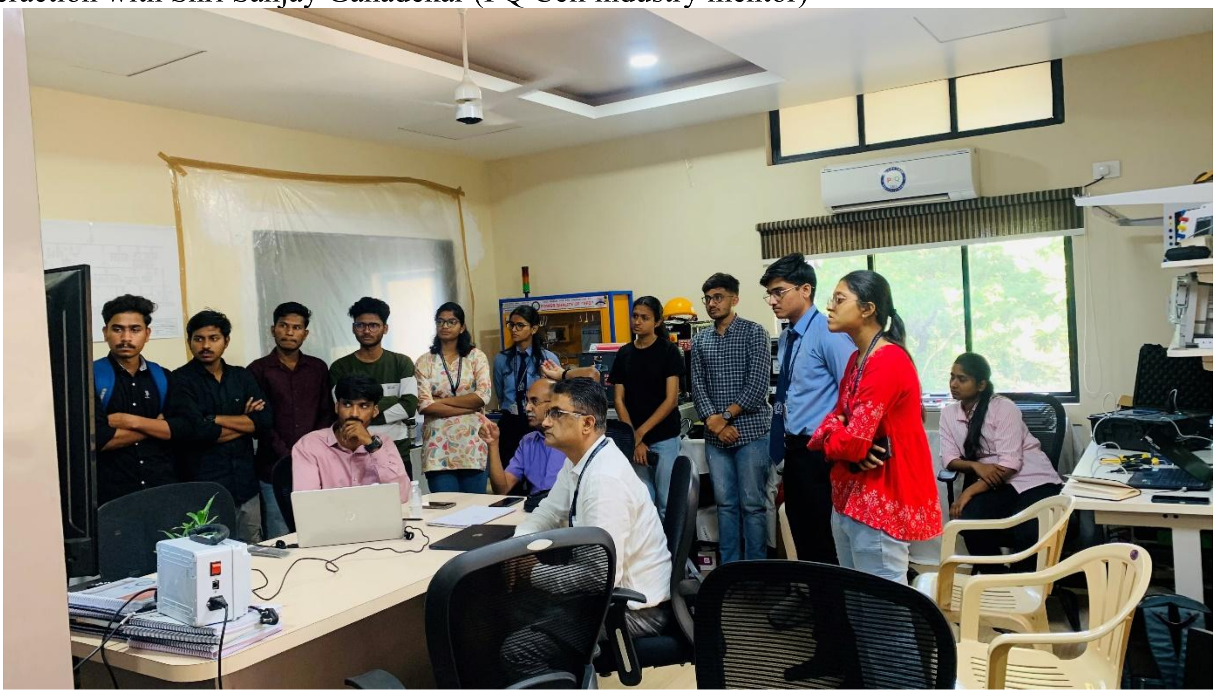
Consultancy offered amount: **Rs. 8.48 Lakhs**
Training provide to : MSEDCL Ganeshkhind Testing Engineers

PQ cell Benefits to Students:

- Internship opportunities provided: Total of Students 06
- Total Final Year Projects – 04
- Products developed – 08
- Hands-on experience opportunities provided – 25 students.
- Placements – 02

Any photos :

Interaction with Shri Sanjay Ganadekar (PQ Cell industry mentor)



Visit of ENTES Turkey team to PQ Cell

PQ Audit at Logicon Technosolutions, Chinchwad

PQ Audit at FHHL, Hadapsar

Best regards
Sachin Shelar

PUZZLES AND QUIZ

Puzzles & Quiz

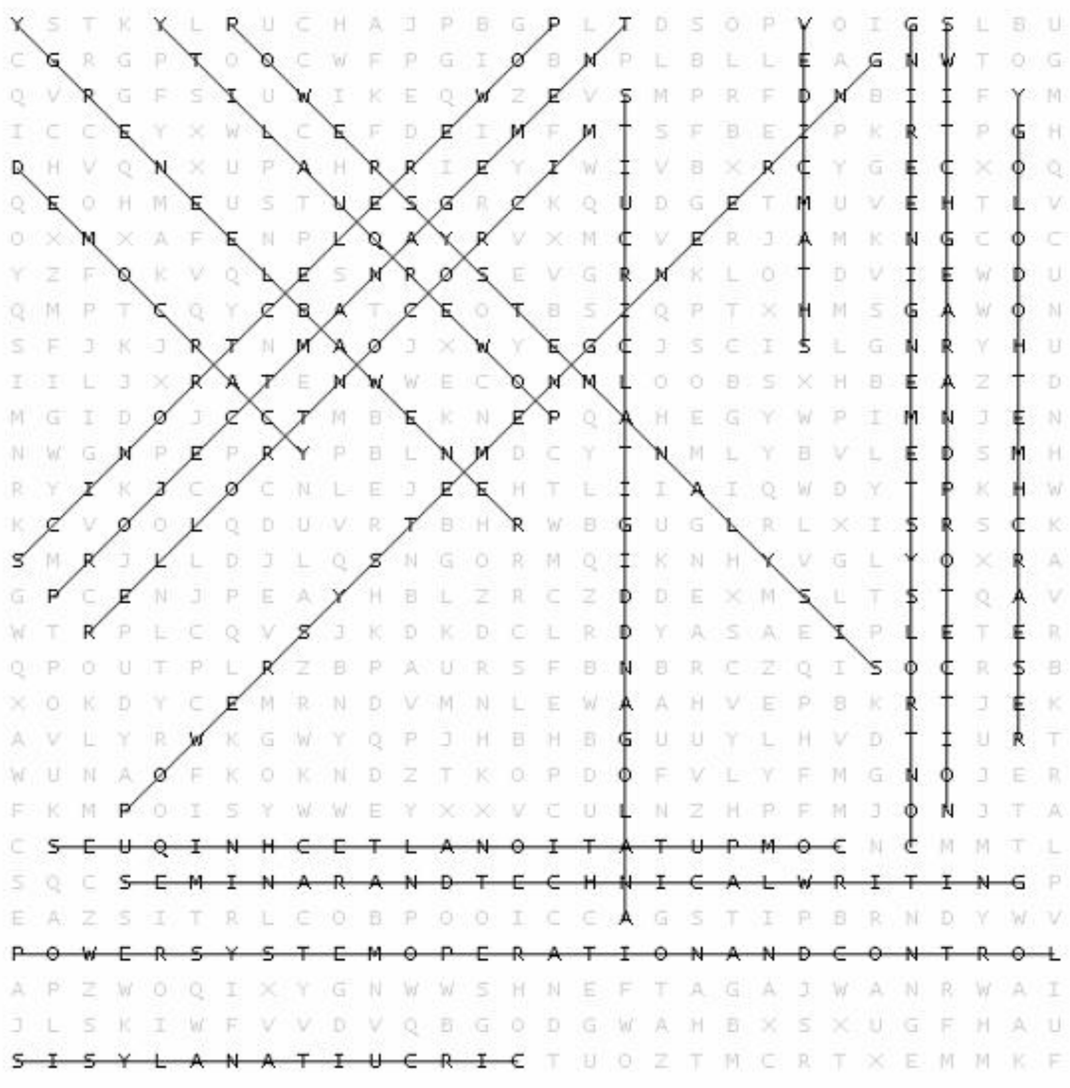
1) Watt’s the Word

Dr. Krutuja S.Gadgil
Assistant Professor

Unlock seventeen electrical engineering subjects from your curriculum.

Y	S	T	K	Y	L	P	U	C	H	A	J	P	B	G	P	L	T	D	S	O	P	V	O	I	G	S	L	B	U
C	G	R	G	P	T	O	O	C	W	F	P	G	I	O	B	N	P	L	B	L	L	E	A	G	N	W	T	O	G
Q	V	R	G	F	S	I	U	W	I	K	E	Q	W	Z	E	V	S	M	P	R	F	D	N	B	I	I	F	Y	M
I	C	C	E	Y	X	W	L	C	E	F	D	E	I	M	F	M	T	S	F	B	E	I	P	K	R	T	P	G	H
D	H	V	Q	N	X	U	P	A	H	R	R	I	E	Y	I	W	I	V	B	X	R	C	Y	G	E	C	X	O	Q
Q	E	O	H	M	E	U	S	T	U	E	S	G	R	C	K	Q	U	D	G	E	T	M	U	V	E	H	T	L	V
O	X	M	X	A	F	E	N	P	L	Q	A	Y	R	V	X	M	C	V	E	R	J	A	M	K	N	G	C	O	C
Y	Z	F	O	K	V	Q	L	E	S	N	R	O	S	E	V	G	R	N	K	L	O	T	D	V	I	E	W	D	U
Q	M	P	T	C	Q	Y	C	B	A	T	C	E	O	T	B	S	I	Q	P	T	X	H	M	S	G	A	W	O	N
S	F	J	K	J	R	T	N	M	A	O	J	X	W	Y	E	G	C	J	S	C	I	S	L	G	N	R	Y	H	U
I	I	L	J	X	R	A	T	E	N	W	W	E	C	O	N	M	L	O	O	B	S	X	H	B	E	A	Z	T	D
M	G	I	D	O	J	C	C	T	M	B	E	K	N	E	P	Q	A	H	E	G	Y	W	P	I	M	N	J	E	N
N	W	G	N	P	E	P	R	Y	P	B	L	N	M	D	C	Y	T	N	M	L	Y	B	V	L	E	D	S	M	H
R	Y	I	K	J	C	O	C	N	L	E	J	E	E	H	T	L	I	I	A	I	Q	W	D	Y	T	P	K	H	W
K	C	V	O	O	L	Q	D	U	V	R	T	B	H	R	W	B	G	U	G	L	R	L	X	I	S	R	S	C	K
S	M	R	J	L	L	D	J	L	Q	S	N	G	O	R	M	Q	I	K	N	H	Y	V	G	L	Y	O	X	R	A
G	P	C	E	N	J	P	E	A	Y	H	B	L	Z	R	C	Z	D	D	E	X	M	S	L	T	S	T	Q	A	V
W	T	R	P	L	C	Q	V	S	J	K	D	K	D	C	L	R	D	Y	A	S	A	E	I	P	L	E	T	E	R
Q	P	O	U	T	P	L	R	Z	B	P	A	U	R	S	F	B	N	B	R	C	Z	Q	I	S	O	C	R	S	B
X	O	K	D	Y	C	E	M	R	N	D	V	M	N	L	E	W	A	A	H	V	E	P	B	K	R	T	J	E	K
A	V	L	Y	R	W	K	G	W	Y	Q	P	J	H	B	H	B	G	U	U	Y	L	H	V	D	T	I	U	R	T
W	U	N	A	O	F	K	O	K	N	D	Z	T	K	O	P	D	O	F	V	L	Y	F	M	G	N	O	J	E	R
F	K	M	P	O	I	S	Y	W	W	E	Y	X	X	V	C	U	L	N	Z	H	P	F	M	J	O	N	J	T	A
C	S	E	U	Q	I	N	H	C	E	T	L	A	N	O	I	T	A	T	U	P	M	O	C	N	C	M	M	T	L
S	Q	C	S	E	M	I	N	A	R	A	N	D	T	E	C	H	N	I	C	A	L	W	R	I	T	I	N	G	P
E	A	Z	S	I	T	R	L	C	O	B	P	O	O	I	C	C	A	G	S	T	I	P	B	R	N	D	Y	W	V
P	O	W	E	R	S	Y	S	T	E	M	O	P	E	R	A	T	I	O	N	A	N	D	C	O	N	T	R	O	L
A	P	Z	W	O	Q	I	X	Y	G	N	W	W	S	H	N	E	F	T	A	G	A	J	W	A	N	R	W	A	I
J	L	S	K	I	W	F	V	V	D	V	Q	B	G	O	D	G	W	A	H	B	X	S	X	U	G	F	H	A	U
S	I	S	Y	L	A	N	A	T	I	U	C	R	I	C	T	U	O	Z	T	M	C	R	T	X	E	M	M	K	F

Solution



2) PUZZLE

By: Pranav Rathod

S	M	A	R	T	G	R	I	D	Q	W	E	R	T	Y	F	D	A
E	F	T	Y	H	I	O	T	R	Y	H	F	G	J	K	U	I	E
E	L	E	C	T	R	O	N	I	C	S	B	A	T	T	E	R	Y
W	I	N	D	V	B	N	H	R	E	N	E	W	A	B	L	E	X
N	A	R	D	I	G	I	T	A	L	T	W	I	N	S	Y	X	H
M	I	C	R	O	G	R	I	D	P	R	A	N	A	V	S	K	H
S	I	L	I	C	O	N	C	A	R	B	O	N	A	T	E	T	Y
O	R	I	S	O	L	I	D	S	T	A	T	E	E	E	H	J	R
L	O	U	I	A	R	T	I	F	I	C	I	A	L	R	T	F	T
A	R	Y	U	I	N	T	E	L	L	I	G	E	N	C	E	G	U
R	E	N	E	R	G	Y	S	T	O	R	A	G	E	R	R	H	H
D	T	P	O	W	E	R	Q	U	A	L	I	T	Y	D	G	U	P
A	E	N	E	R	G	Y	S	T	O	R	A	G	E	F	H	U	O
N	Y	S	M	A	R	T	M	E	T	E	R	H	T	G	I	G	K
C	P	R	A	N	A	V	P	A	T	I	W	E	R	H	J	C	J
E	W	R	E	L	E	C	T	R	I	C	V	E	H	I	C	L	E
F	G	R	I	D	M	O	D	U	L	A	T	I	O	N	F	U	C
U	Q	W	D	F	H	Y	U	I	D	V	C	C	O	N	V	I	N

1. Modern electricity network that uses digital communication to detect and react to changes in energy usage.
2. A technology that connects everyday devices to the internet for monitoring and control.
3. Technology that enables machines to mimic human intelligence and decision-making.
4. Branch of electrical engineering dealing with conversion and control of electrical power.
5. Advanced semiconductor material used in high-efficiency power devices.
6. A small-scale, localized power grid that can operate independently of the main grid.

7. Device that stores chemical energy and converts it to electrical energy.
8. High-voltage direct current transmission system used for long-distance power transfer.
9. Virtual model of a physical system used for monitoring, simulation, and optimization.
10. The capacity to do work; in electrical engineering, it powers devices and systems.
11. Energy source that naturally replenishes, like solar, wind, or hydro.
12. Energy harvested from sunlight using photovoltaic cells.
13. Energy generated using turbines powered by moving air.
14. Measure of the reliability and stability of electrical power supplied to consumers.
15. Device that records electricity usage and communicates it to utilities digitally.
16. Technology based on semiconductors with no moving parts, e.g., transistors.
17. Vehicles powered entirely or partially by electricity instead of fossil fuels.
18. Advanced computer algorithms that learn, reason, and predict outcomes.
19. Systems or devices used to store electricity for later use.
20. Upgrading the electrical grid for efficiency, reliability, and smart operation.

Quiz Corner: Latest Trends in Electrical Engineering

Prepared by- Ms. Saba K M Shaikh

Test your knowledge and discover fun facts about modern Electrical Engineering!

1. The main objective of a *Smart Grid* is to:
   a) Increase conductor size
   b) Enable one-way power flow
   c) Integrate communication, control, and power systems
   d) Eliminate renewable energy sources

2. Which device provides time-synchronized measurements for wide-area monitoring of power systems?
   a) Smart Meter
   b) PMU (Phasor Measurement Unit)
   c) Energy Meter
   d) PLC

3. Wide Band Gap semiconductor devices such as SiC and GaN are preferred because they:
   a) Operate only at low voltage
   b) Have low efficiency
   c) Can operate at high temperature and high frequency
   d) Are cheaper than silicon devices

4. Vehicle-to-Grid (V2G) technology enables electric vehicles to:
   a) Charge faster only
   b) Operate without batteries
   c) Supply power back to the grid
   d) Use only solar energy

5. Which standard is commonly used in *digital substations* for communication and protection?
   a) IEEE 802.11
   b) Modbus
   c) IEC 61850
   d) RS-232

6. Artificial Intelligence in power systems is mainly applied for:
   a) Manual switching operations
   b) Load forecasting and fault diagnosis
   c) Manufacturing of transformers
   d) Transmission line erection

7. A micro grid can be best described as:

   a) A small transmission network
   b) A backup diesel generator
   c) A localized system with loads and distributed generation
   d) A nuclear power plant

8. Which energy storage technology is most widely used in electric vehicles?
   a) Lead-acid batteries
   b) Nickel-metal hydride batteries
   c) Lithium-ion batteries
   d) Zinc-air batteries

9. IoT in Electrical Engineering is mainly used for:
   a) Increasing conductor weight
   b) Real-time monitoring and control of electrical systems
   c) Manual meter reading
   d) Reducing insulation level

10. The biggest challenge in large-scale renewable energy integration is:
   a) High efficiency
   b) Predictable generation
   c) Intermittency and grid stability
   d) Low initial cost

Did You Know?

- A Smart Meter can record electricity usage at intervals as small as 15 minutes and send data automatically to utilities.
- Phasor Measurement Units (PMUs) can measure voltage and current angles with accuracy up to 1 microsecond using GPS.
- An electric vehicle battery can power a typical Indian household for 1–2 days using V2G technology.
- SiC-based power converters can reduce energy losses by nearly 50% compared to conventional silicon devices.

Fun Facts for Students

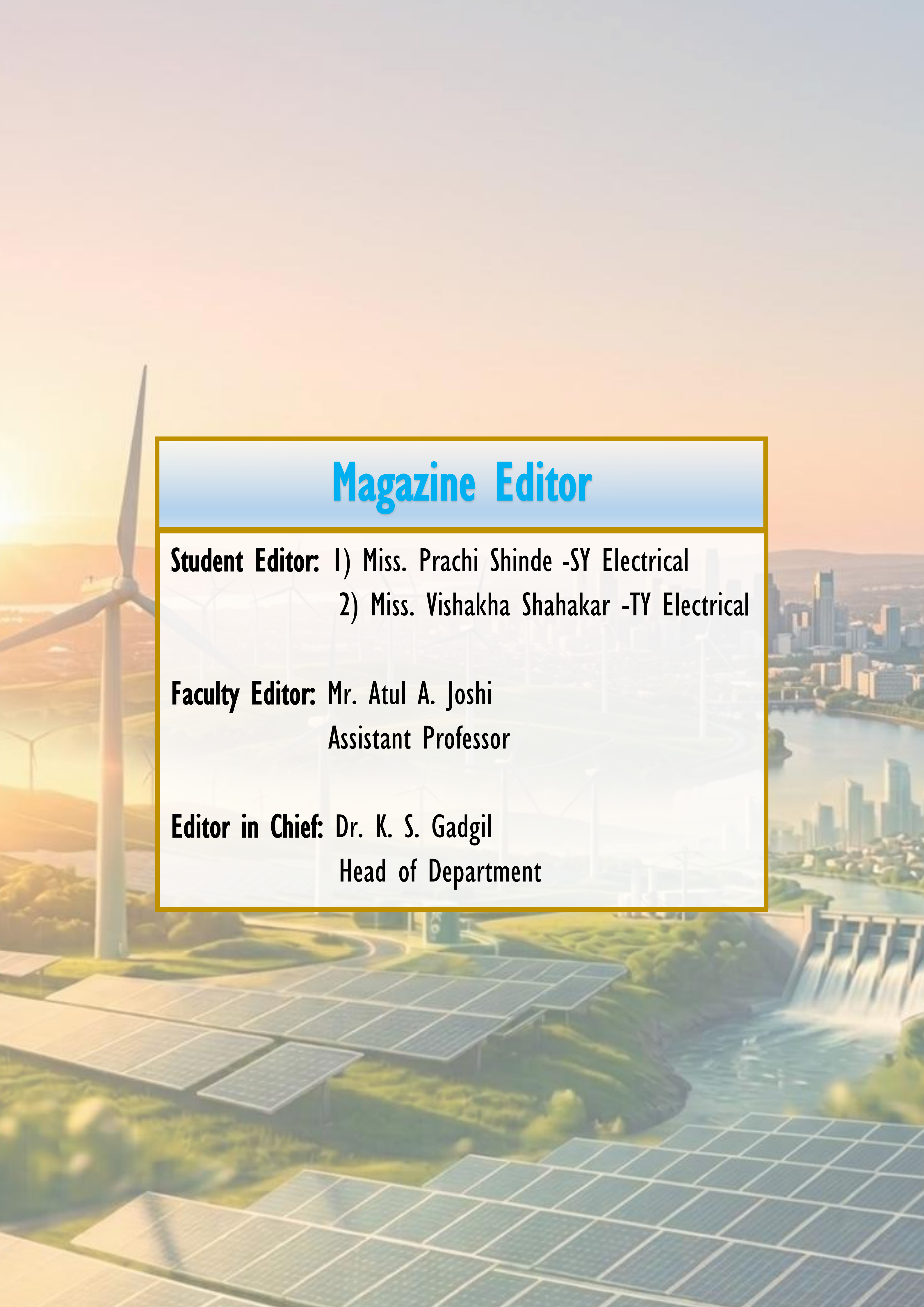
- India's first **fully digital substation** operates with almost *no copper wiring*.
- One fast EV charger can consume power equivalent to **50–60 homes** running simultaneously.
- AI-based fault detection can identify grid disturbances **before humans notice them**.
- A single wind turbine blade can be **longer than a football field**!

Challenge Yourself!

Score 8 or above and you're already thinking like a future power engineer

Answer Key

1–c, 2–b, 3–c, 4–c, 5–c, 6–b, 7–c, 8–c, 9–b, 10-c



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